



US007075709B2

(12) **United States Patent**
Nakamura et al.

(10) **Patent No.:** **US 7,075,709 B2**
(45) **Date of Patent:** **Jul. 11, 2006**

(54) **OPTICAL TRANSMISSION SYSTEM,
OPTICAL REPEATER, AND OPTICAL
TRANSMISSION METHOD**

2003/0016437 A1* 1/2003 Islam et al. 359/334

FOREIGN PATENT DOCUMENTS

(75) Inventors: **Kentaro Nakamura**, Kawasaki (JP);
Takafumi Terahara, Kawasaki (JP);
Rainer Hainberger, Kawasaki (JP);
Junichi Kumasako, Kawasaki (JP)

CN	1279549 A	1/2001
EP	1 018 666 A1	7/2000
EP	1 076 434 A2	2/2001
JP	3-239028	10/1991
JP	2000-330145	11/2000
WO	WO 00/49721	8/2000
WO	WO 01/65737	9/2001

(73) Assignee: **Fujitsu Limited**, Kawasaki (JP)

OTHER PUBLICATIONS

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

Agrawal, Govind P. *Fiber-Optic Communication Systems*. Second Edition. John Wiley & Sons, Inc. 1997. pp. 323-325.*

(21) Appl. No.: **10/103,690**

(Continued)

(22) Filed: **Mar. 25, 2002**

Primary Examiner—Deandra M. Hughes

(74) *Attorney, Agent, or Firm*—Staas & Halsey LLP

(65) **Prior Publication Data**

US 2003/0117693 A1 Jun. 26, 2003

(30) **Foreign Application Priority Data**

Dec. 20, 2001 (JP) 2001-388097

(51) **Int. Cl.**
H01S 3/00 (2006.01)

(52) **U.S. Cl.** **359/334**

(58) **Field of Classification Search** 359/334
See application file for complete search history.

(57) **ABSTRACT**

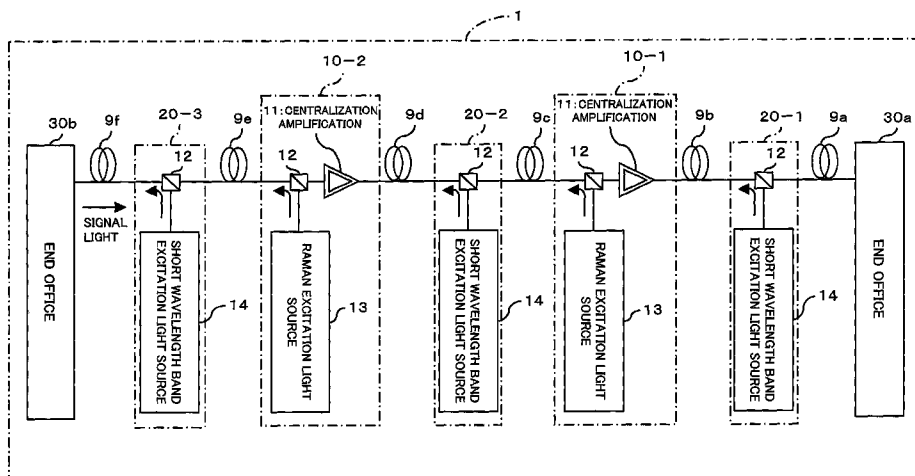
In a WDM transmission system employing a plurality of short wavelength bands having great attenuation due to optical fiber transmission, an optical repeater is constructed of a first multiplexing section and a second multiplexing section. The first multiplexing section is used for wavelength-multiplexing both the excitation light from a first Raman excitation light source, which distributively amplifies an S+ band included in light propagating through an optical fiber, and the light propagating through the optical fiber. The second multiplexing section is used for wavelength-multiplexing both the excitation light from a second Raman excitation light source, which distributively amplifies an S+ band included in light propagating through an optical fiber, and the light propagating through the optical fiber. The first and second multiplexing sections are provided between the optical fibers disposed between end offices. Thus an equal and satisfactory optical SN ratio even at any band are obtained.

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,356,383 B1*	3/2002	Cornwell et al.	359/334
6,574,037 B1*	6/2003	Islam et al.	359/334
6,587,259 B1*	7/2003	Islam et al.	359/334
6,614,586 B1*	9/2003	Hayee et al.	359/334
6,633,712 B1*	10/2003	Dennis et al.	385/123
2001/0003486 A1*	6/2001	Mikami	359/161
2002/0105715 A1*	8/2002	Naito et al.	359/334
2002/0131131 A1*	9/2002	Nagel et al.	359/173

7 Claims, 17 Drawing Sheets



OTHER PUBLICATIONS

Merriam-Webster's Collegiate Dictionary. Merriam-Webster, Inc. 10th Edition. p. 79.*
Islam, Mohammed. Raman Amplifiers for Telecommunications. IEEE Journal of Selected Topics in Quantum Electronics. vol. 8. No. 3. May/June. 2002. pp. 548-559.*
The Patent Office of The People's Republic of China, Notification of the First Office Action dated Oct. 29, 2004.
Tutaka Yano et al., "Experimental Study on SRS Loss and Its Compensation in Three-Band WDM Transmission", Pro-

ceeding of the European Conference on Optical Communication, 2000, pp. 39-40, XP001023917.

X.Y. Zou et al., "Compensation of Nonuniform Gain Induced by Raman Scattering and EDFAs in Ultralong-Distance WDM Links", vol. 8, Feb. 26, 1995, pp. 152-153, XP000517683.

European Search Report for Application No. 02007244.3-1246, dated Jun. 21, 2005.

* cited by examiner

FIG. 1

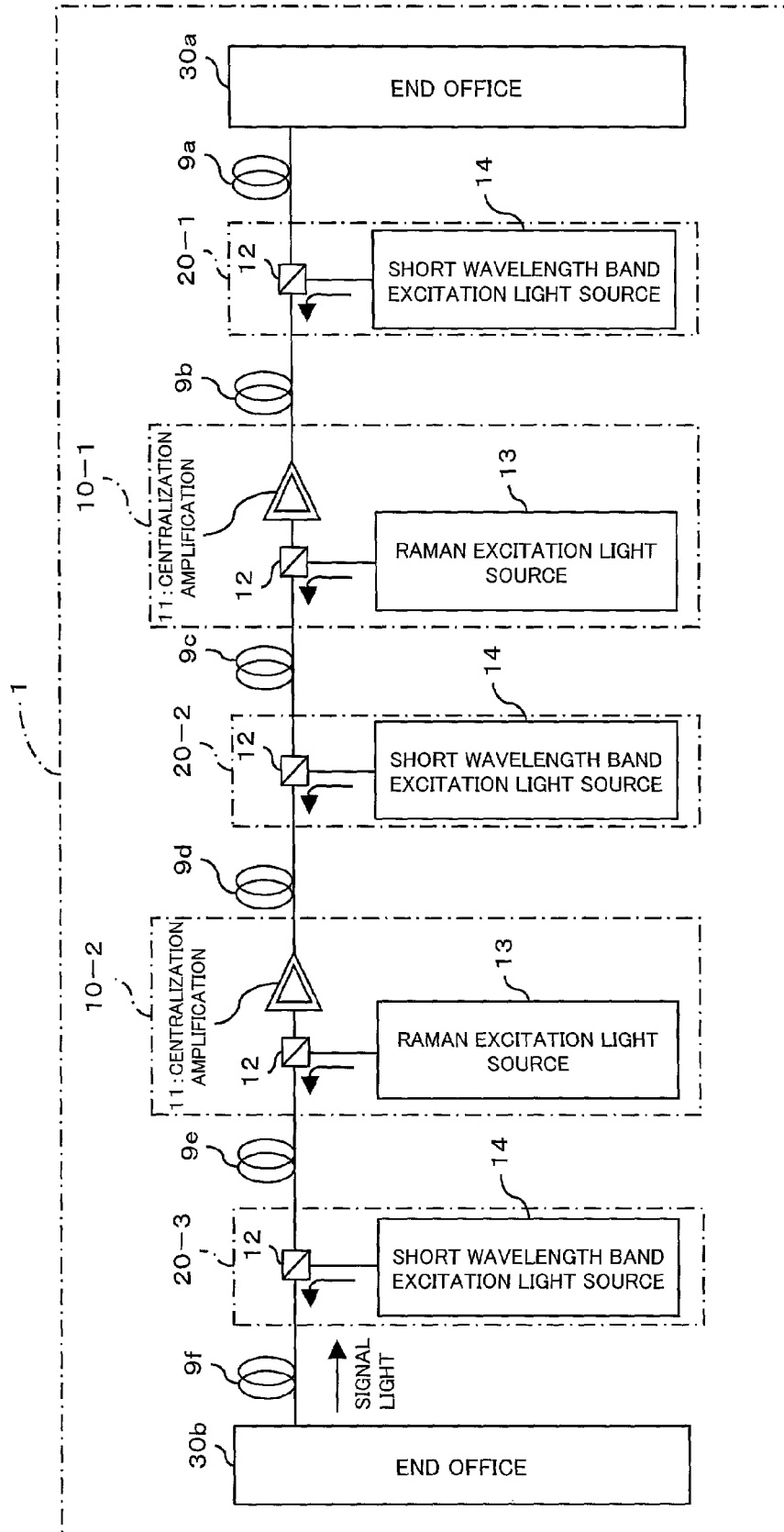


FIG. 2B
PRIOR ART

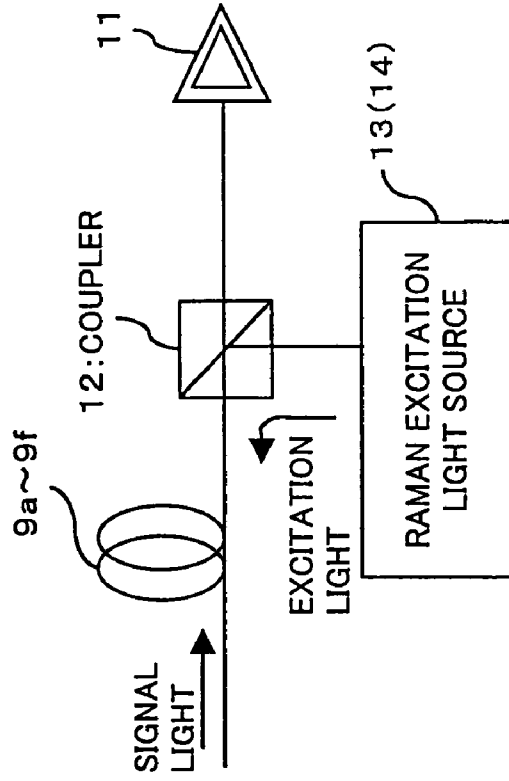


FIG. 2A
PRIOR ART

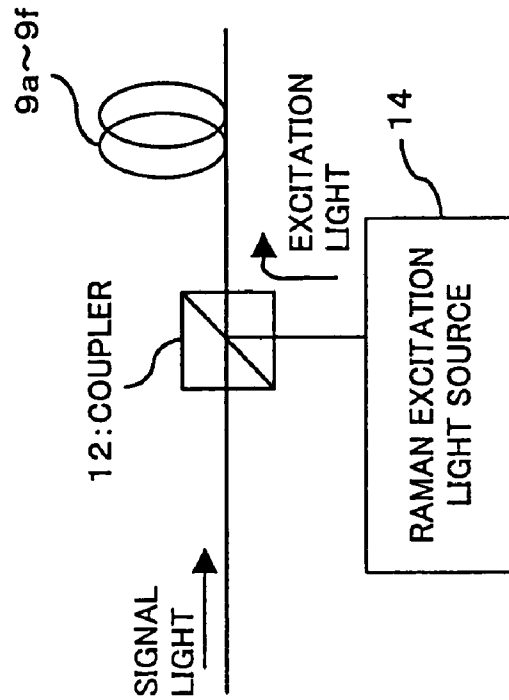


FIG. 3

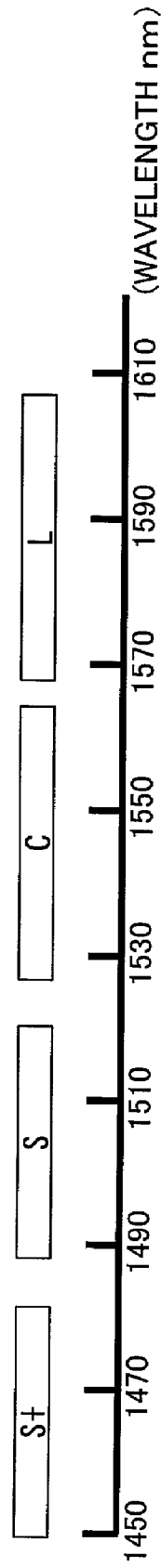


FIG. 4

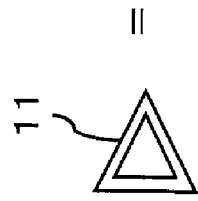
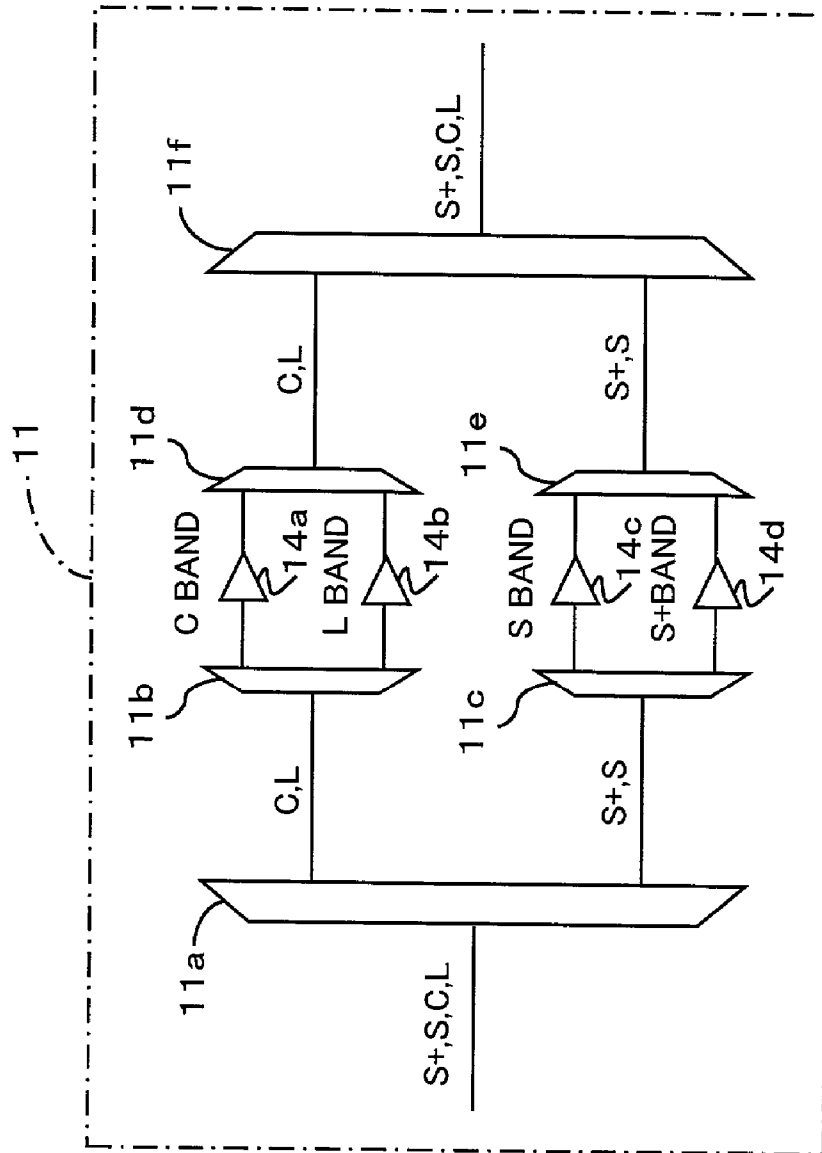


FIG. 5

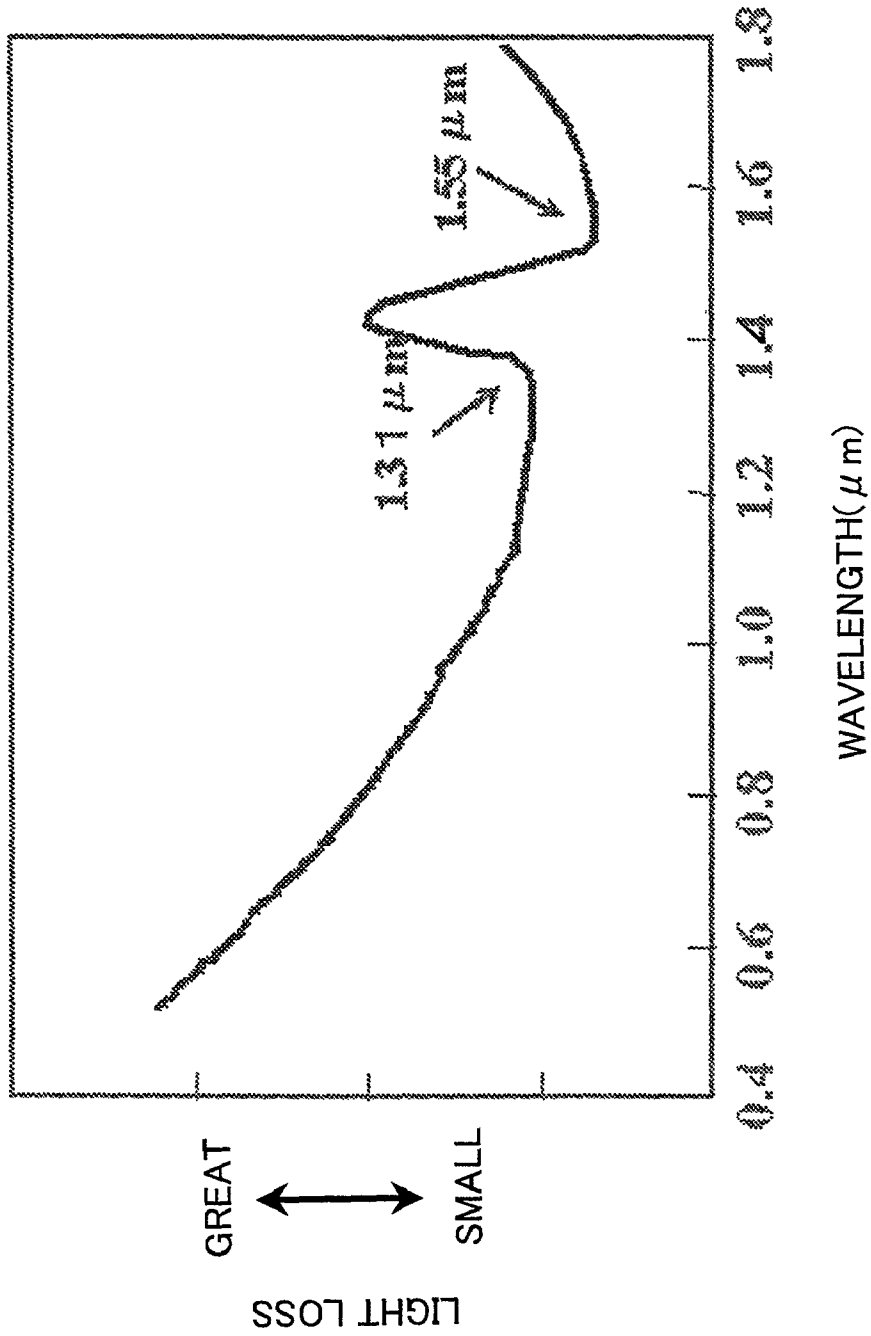


FIG. 6B

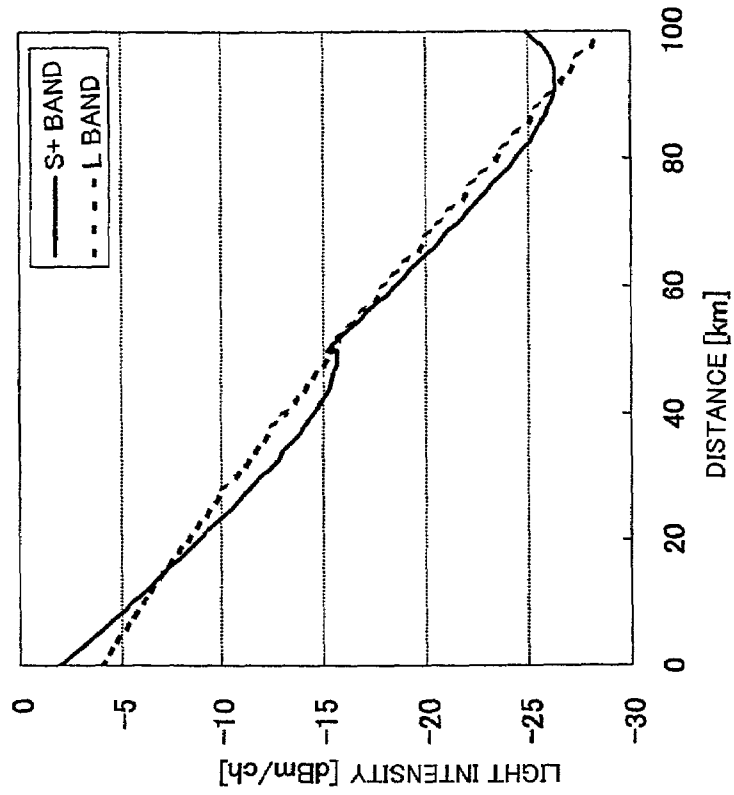


FIG. 6A

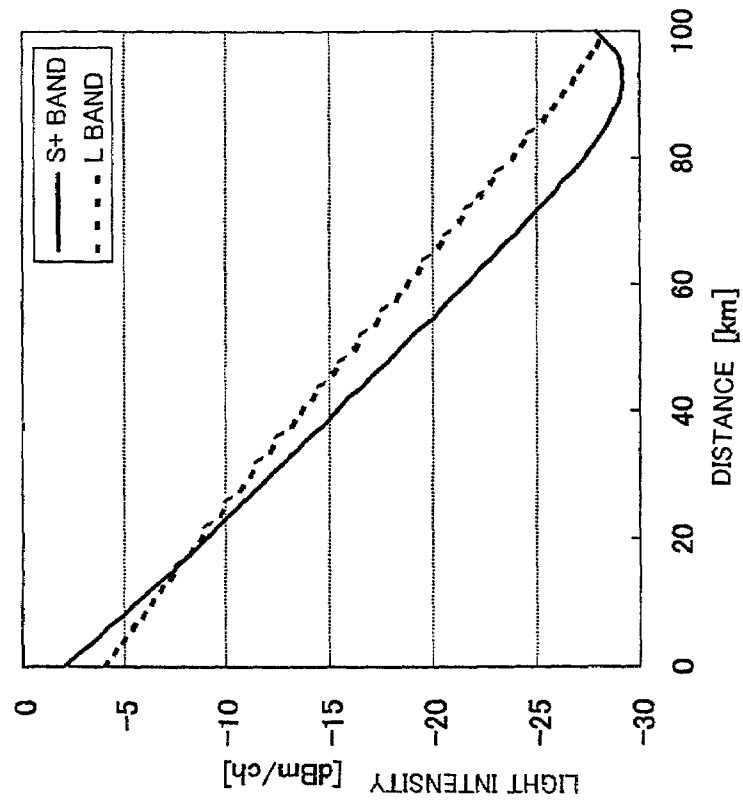


FIG. 7

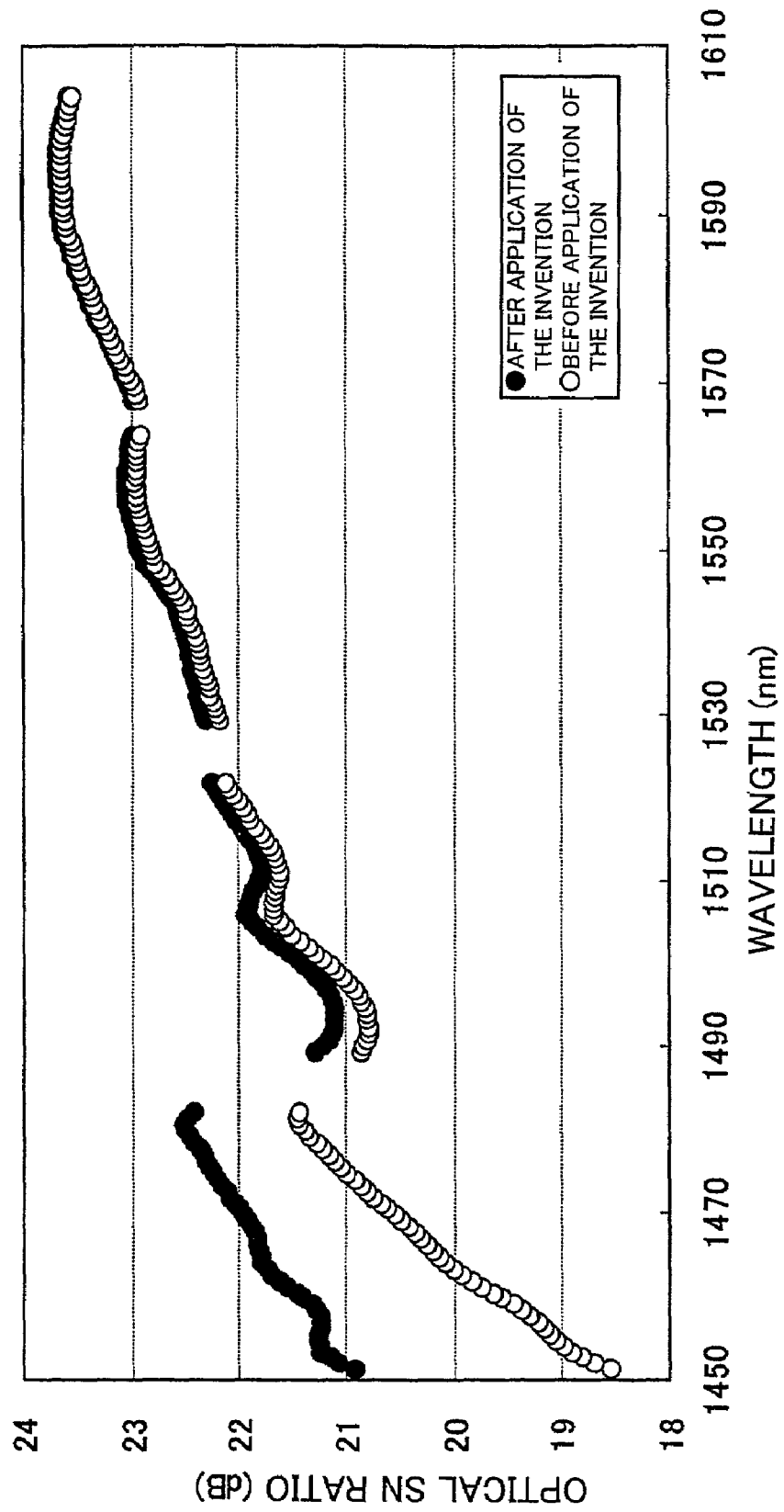


FIG. 8

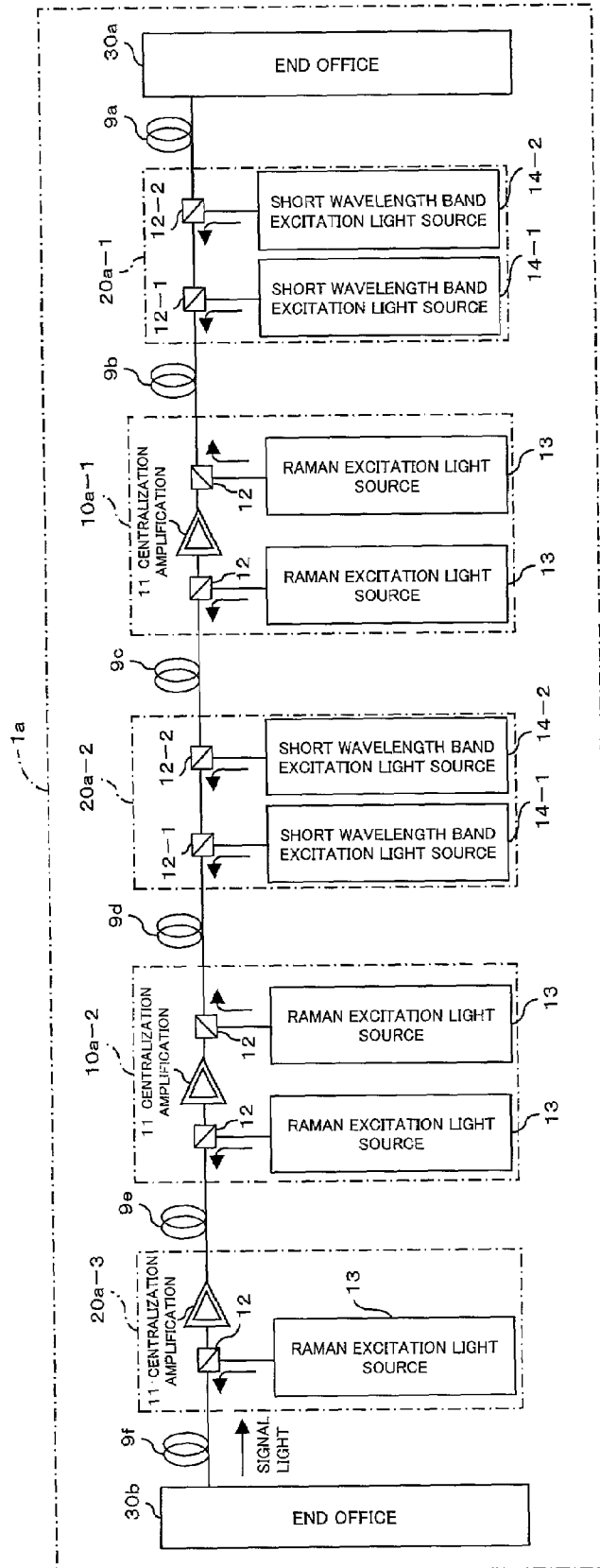


FIG. 9

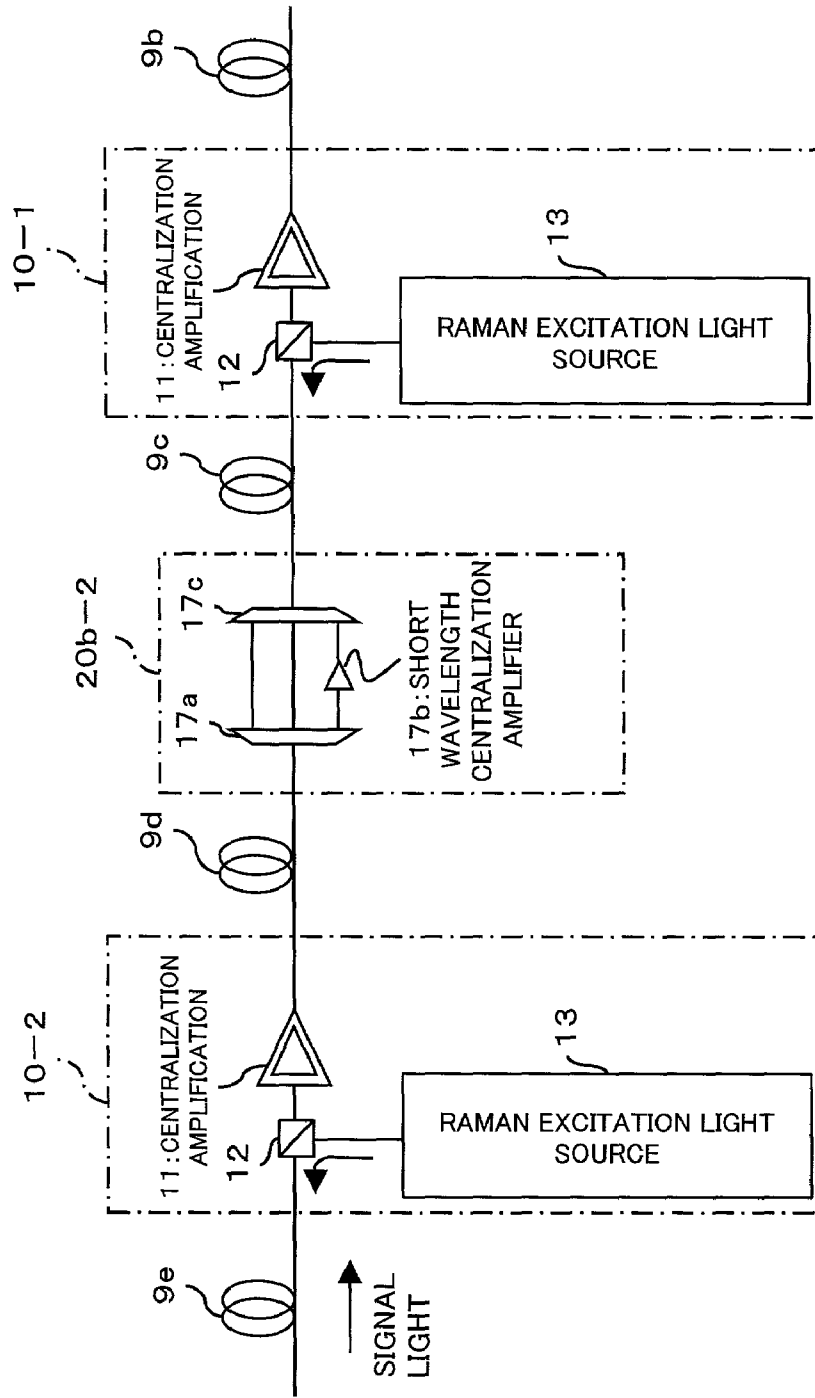


FIG. 10

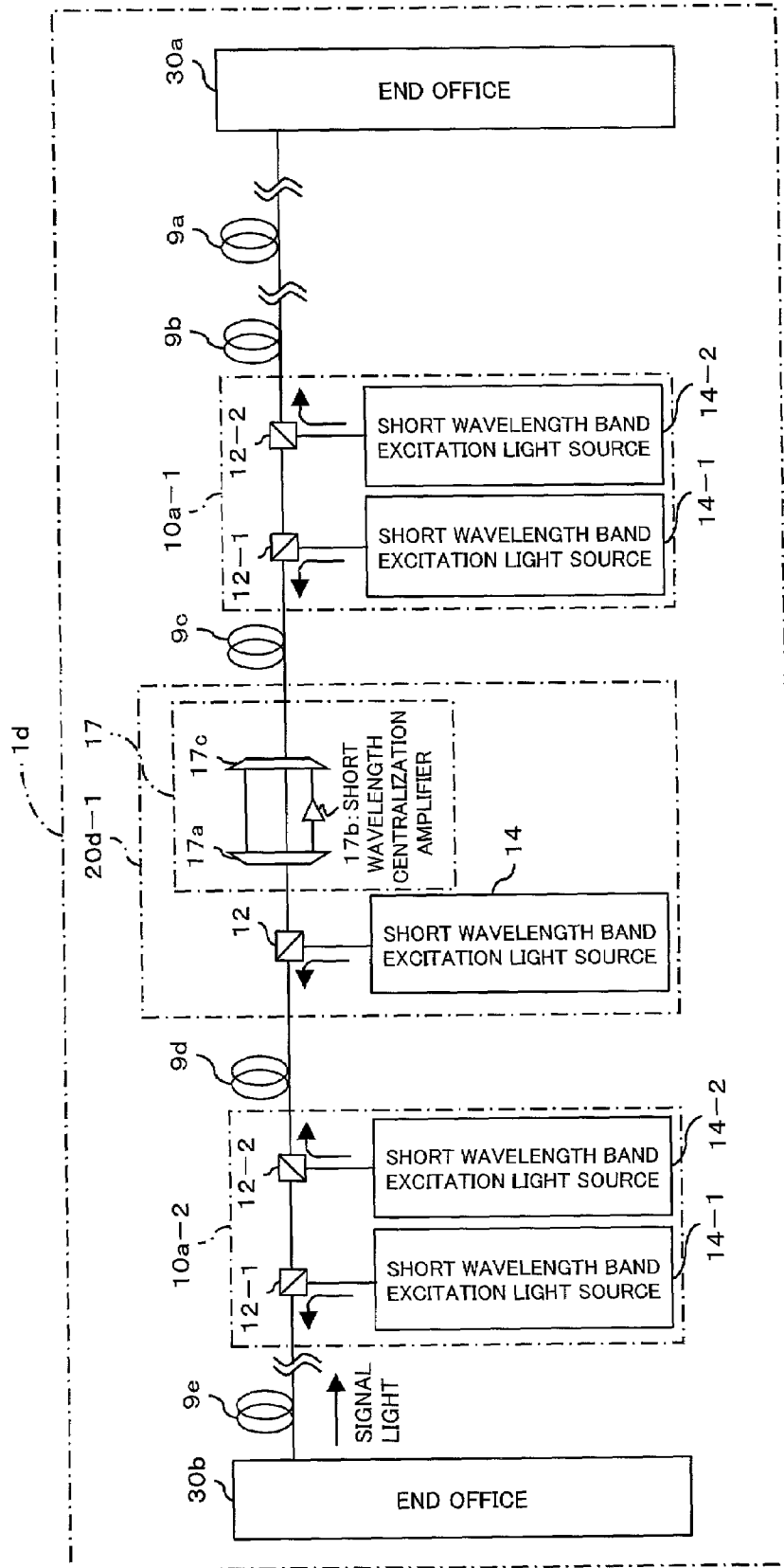


FIG. 11

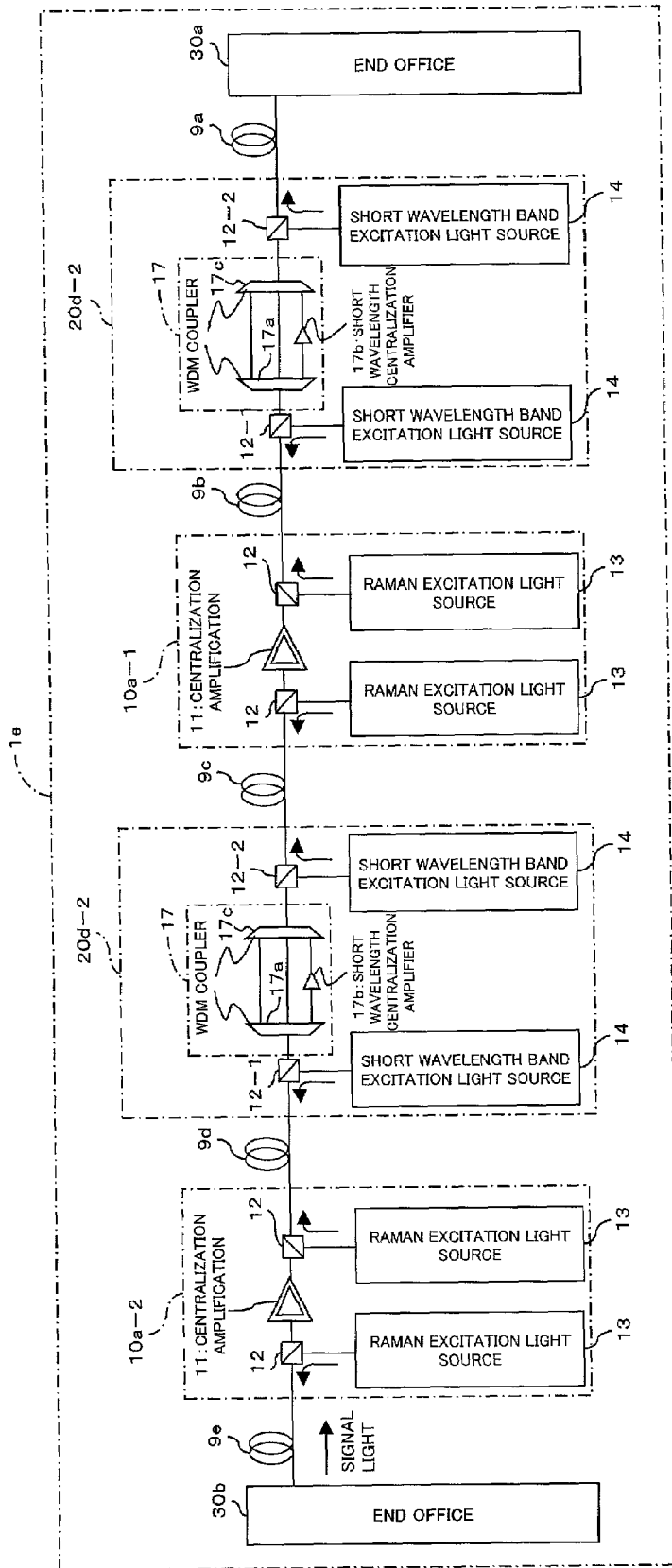


FIG. 13

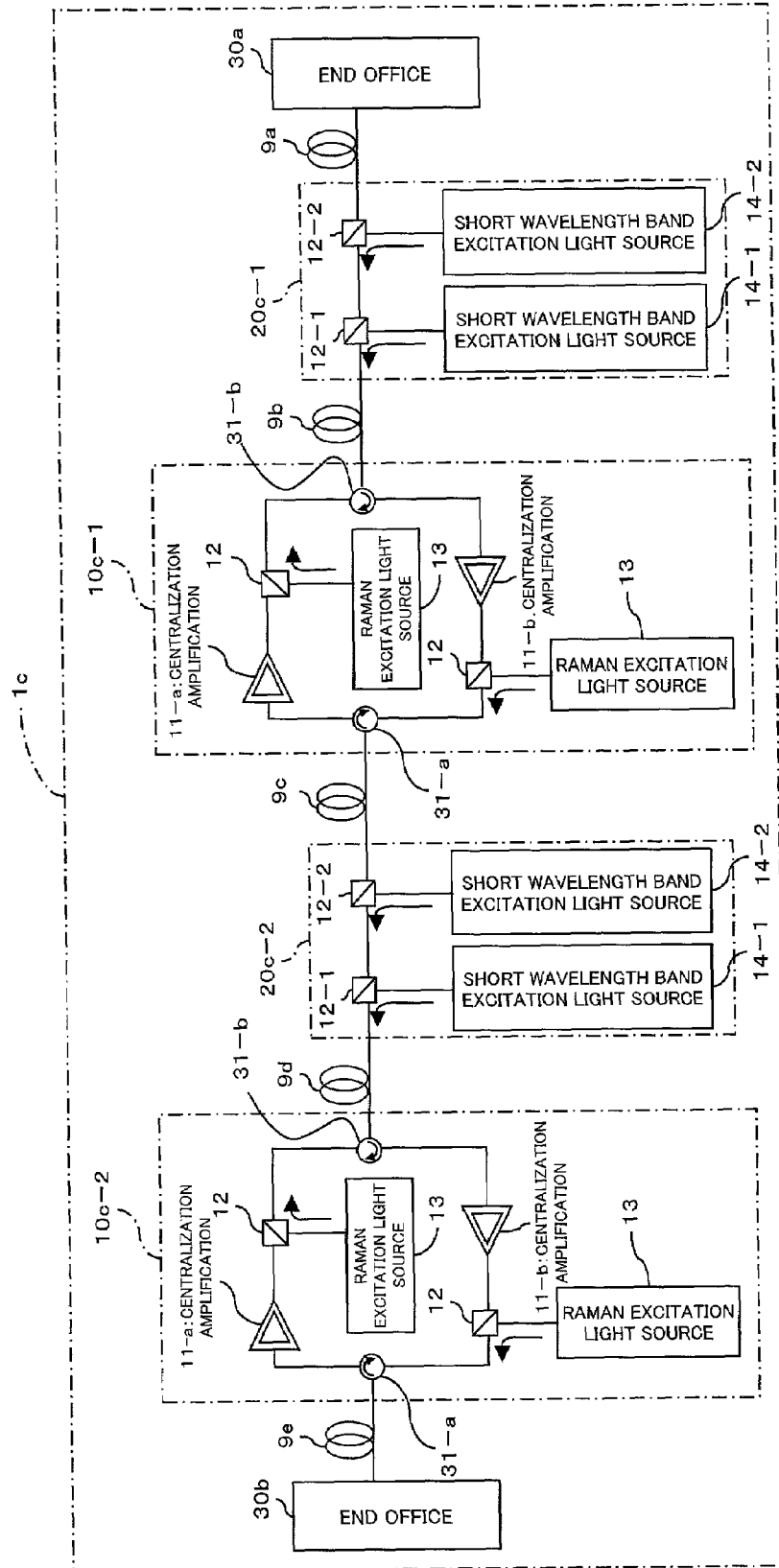


FIG. 14

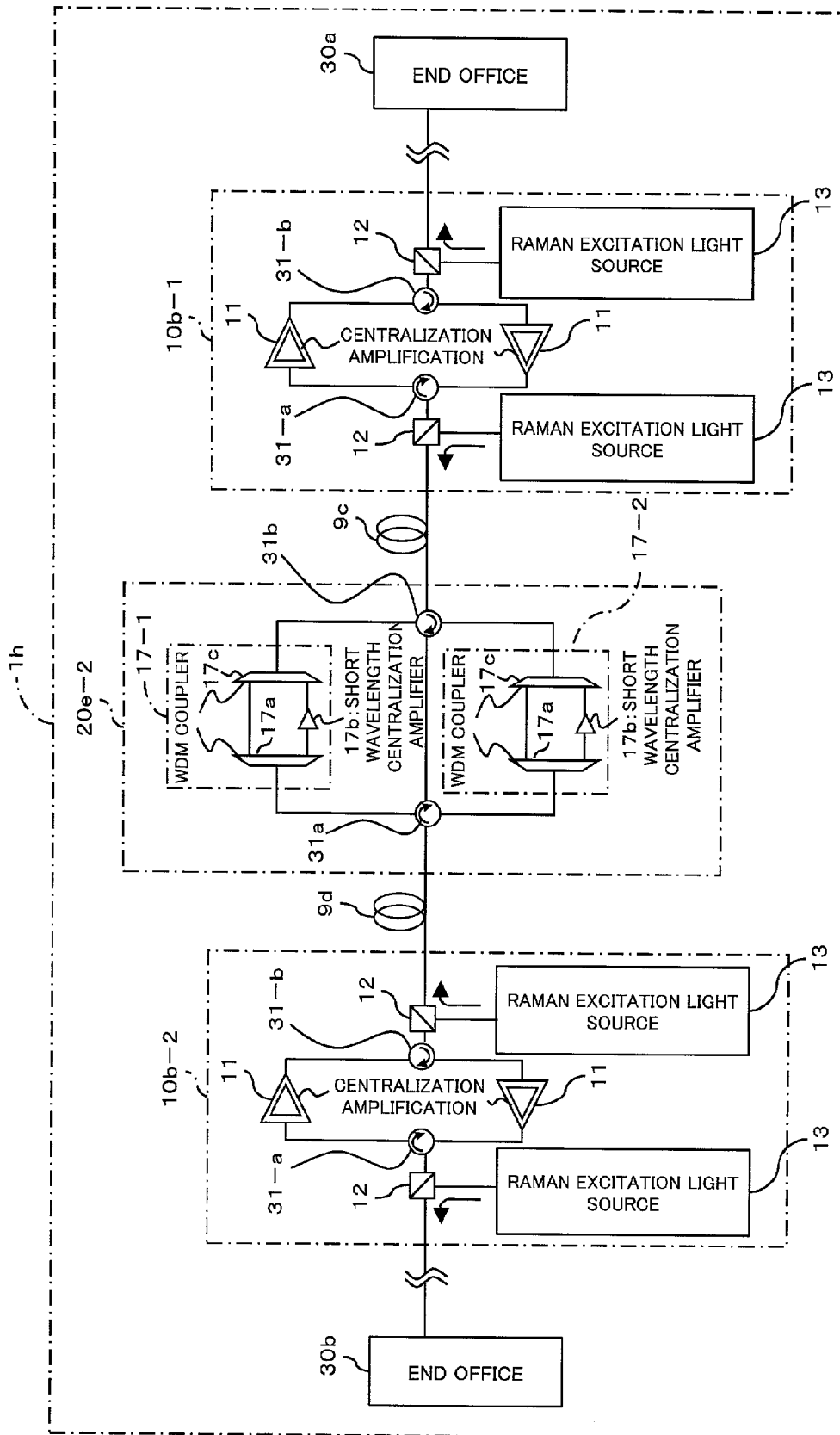


FIG. 15

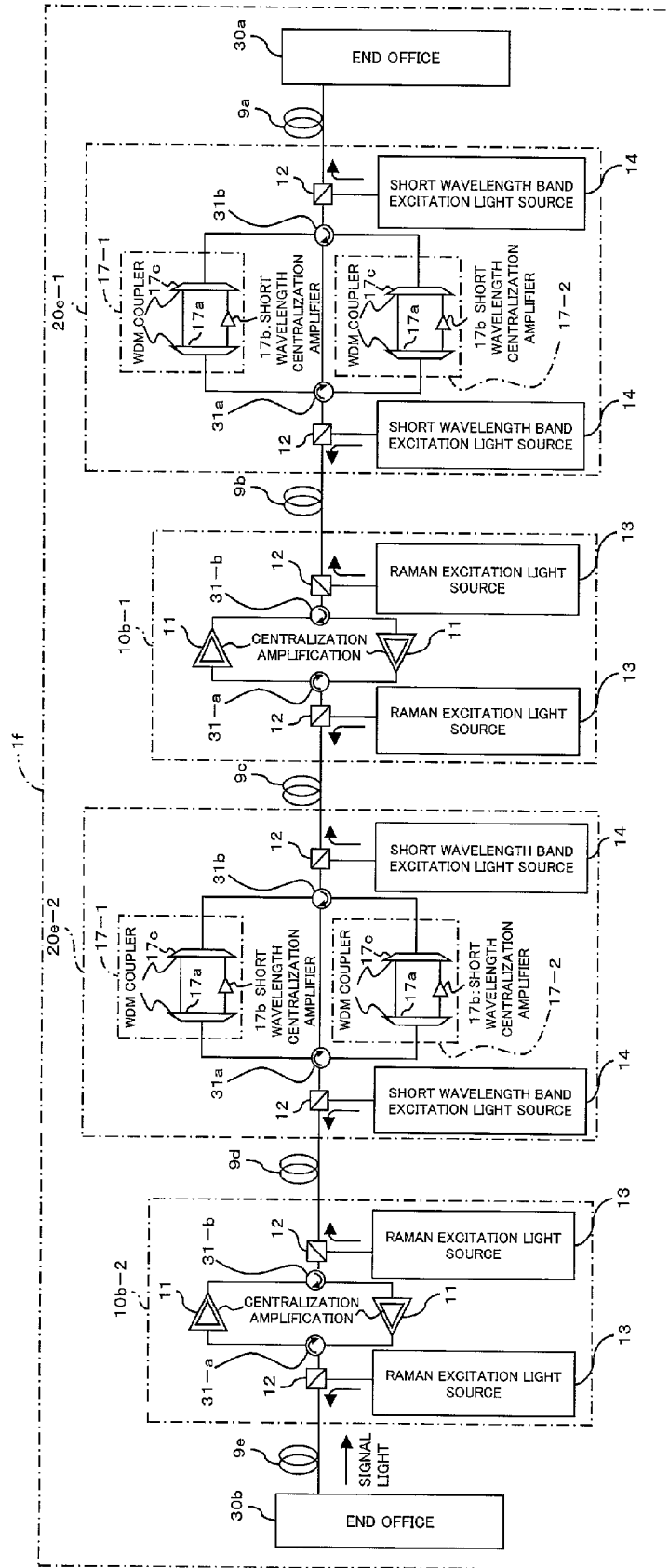


FIG. 16

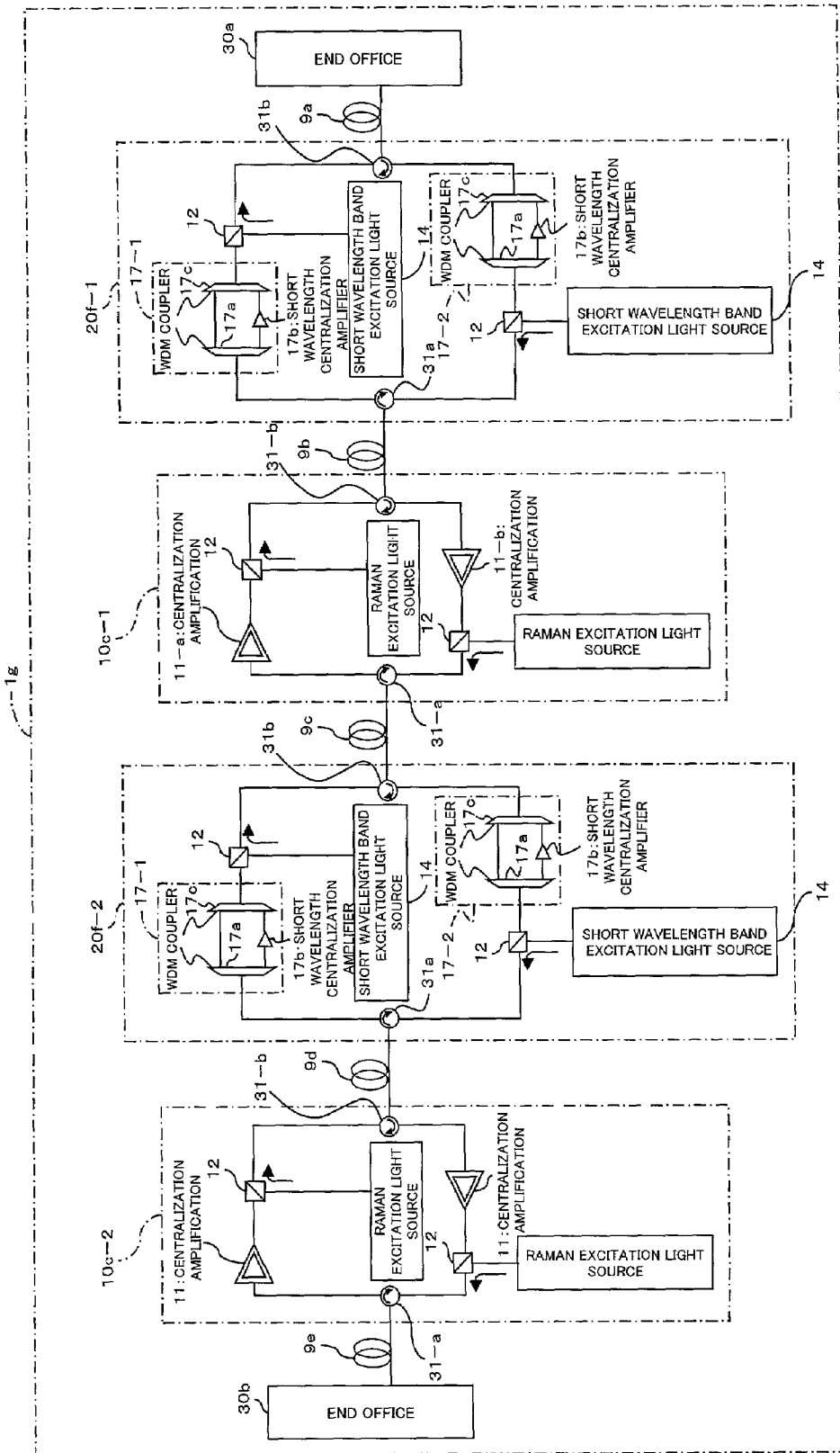


FIG. 17C
PRIOR ART

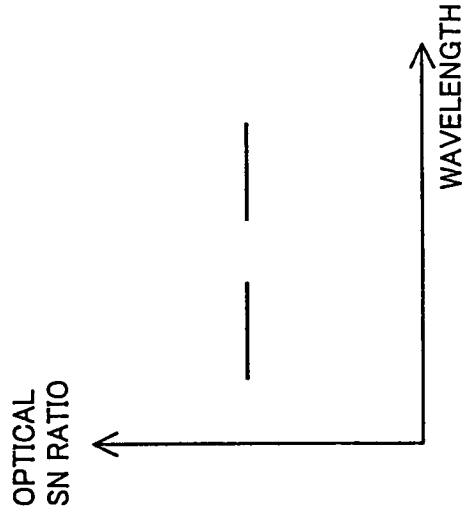


FIG. 17B
PRIOR ART

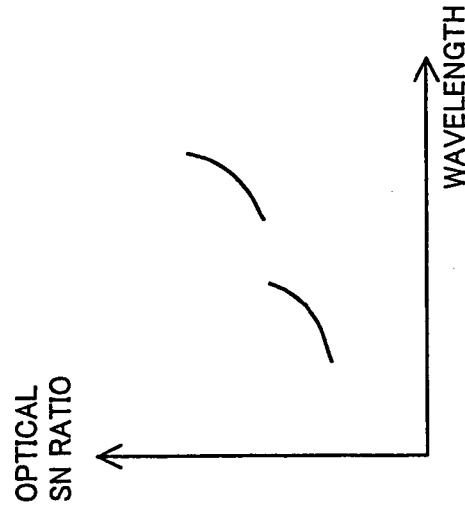
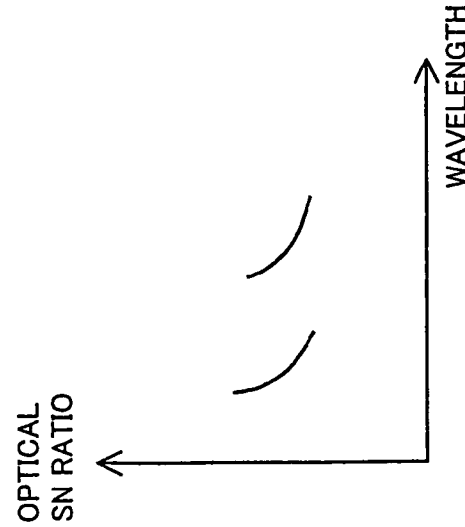


FIG. 17A
PRIOR ART



**OPTICAL TRANSMISSION SYSTEM,
OPTICAL REPEATER, AND OPTICAL
TRANSMISSION METHOD**

BACKGROUND OF THE INVENTION

(1) Field of the Invention

The present invention relates to an optical transmission system, an optical repeater, and an optical transmission method suitable, for example, for a wavelength division multiplexing (WDM) system employing a short wavelength band.

(2) Description of the Related Art

A WDM system (optical transmission system), which employs a wavelength-multiplexed signal light consisting of a signal light having a plurality of different wavelengths, is being employed to transmit an electrical signal such as voice, data, etc.

In this WDM system, one end office (or one transmission end office) optically modulates and multiplexes electrical signals output from an exchange and transmits the wavelength-multiplexed signal light to an optical repeater of the initial stage. The signal light from the optical repeater is transmitted to a plurality of optical repeaters and is demodulated by the other end office. The demodulated electrical signals are transmitted to other exchanges.

As a conventional method of compensating for an optical signal-to-noise ratio (hereinafter referred to as an optical SN ratio), there is a method of previously emphasizing the optical repeater output of a short wavelength band component by pre-emphasis, or a method of exciting and amplifying this short wavelength band component. The pre-emphasis is the method of equalizing the received optical SN ratios of signal wavelengths by previously reducing at a transmitting side the optical SN ratios of signal wavelengths having less SN ratio degradation.

FIGS. 17A to 17C are diagrams used to explain pre-emphasis, the horizontal axis representing optical wavelengths and the vertical axis representing optical SN ratios. The curve shown in FIG. 17A represents the reception characteristic of a receiving station and shows that the reception characteristic has been degraded at the short wavelength band. The curve shown in FIG. 17B represents a transmission characteristic employing pre-emphasis and shows that a signal light is transmitted after a compensation for transmission degradation is made at a transmitting side. As a result, a flat characteristic is obtained at a receiving side, as indicated by a reception characteristic in FIG. 17C.

If the light power (hereinafter referred to as power) of transmission light to be output from an end office or optical repeater is made too great by the pre-emphasis, a signal light with a plurality of wavelengths will increase the influence of a nonlinear optical effect and develop the nonlinear distortions of cross phase modulation and self-phase modulation, resulting in transmission quality degradation. Because of this, pre-emphasis is often employed in optical auxiliary repeaters.

A general optical repeater is constructed by combination of a centralization amplifier and a distributive amplification. There are two types of centralization amplifiers. One type is an optical fiber, doped with a rare-earth element, such as an erbium-doped fiber (EDF), and light within the optical fiber is excited to optically amplify a transmission signal intensively within the optical fiber. The other type is a dispersion compensation fiber with high nonlinearity in which a transmission signal is intensively amplified by excitation. The centralization amplifier, which employs a fiber doped with a

rare-earth element, is used to amplify transmission light by combination of a specific amplification band that a rare-earth element has and excitation light.

The distributive amplification is the method of employing an excitation light source of specific wavelength and the physical properties of an optical fiber employed as a transmission path, and amplifying a signal light distributively by employing optical repeaters between end offices and between optical repeaters and the entire transmission line between the end offices. The distributive amplification normally employs Raman amplification.

The Raman amplification is the technique of performing optical amplification by employing the Raman scattering effect of an optical fiber itself. In general, a Raman amplifier is used for transmitting light, which has a wavelength about 100 nm shorter than that of a signal light, onto a transmission line to amplify the signal light propagating through the transmission line.

In addition, various techniques related to optical repeaters have been proposed (e.g., Japanese Laid-Open Patent Publication No. 2000-330145 (hereinafter referred to as known reference 1), Japanese Laid-Open Patent Publication No. HEI 3-239028 (hereinafter referred to as known reference 2), etc.).

In the case where WDM transmission is performed with a plurality of wavelength bands, the light energy on the short wavelength side excites the light on the long wavelength side by Stimulated Raman Scattering (SRS). As a result, the intensity of received light on the short wavelength side is reduced and the intensity of received light on the long wavelength side is increased.

In addition, in the case of expanding a wavelength band for WDM transmission by an attenuation characteristic that a normal single-mode fiber has, the light loss is minimized at the C band and L band. On the other hand, in the bands on the short wavelength side and long wavelength side with the C and L bands as the center, the light loss is increased. For the light on a short wavelength side such as a S+ band shown in FIG. 3 to be described later, the light loss is further increased.

Therefore, there is a need to improve the intensity of the light on the short wavelength side where loss due to Stimulated Raman Scattering and loss due to optical fibers are added together.

Because of this, in the case where an end office performs pre-emphasis, an output for a short wavelength band is set high, or the characteristic of a centralization amplifier within an optical repeater is determined so that an output for a short wavelength band becomes high, or the intensity of excitation light for distributive amplification with respect to a short wavelength band is increased.

However, if the output of the signal light is made greater, the influence of a nonlinear optical effect will increase in a transmission line, and because of the influence of Stimulated Brillouin Scattering (SBS), an end office, etc., can input only a fixed quantity of power to an optical fiber. This means that a signal light with a predetermined power cannot be transmitted over an optical fiber.

In the case where power input to an optical fiber is great even if the signal light power at a sender is less than a threshold value for Stimulated Brillouin Scattering, there is a possibility that between a plurality of signal lights, noise will occur due to four light wave mixing or inter phase modulation, etc., and will degrade transmission quality.

In the case of performing distributive amplification by excitation light emitted from an optical repeater, light with a wavelength shorter than the short wavelength of a signal

light (e.g., light with a wavelength about 100 nm shorter than that of a signal light to be amplified) has to be employed as excitation light. This is because light on a short wavelength side is greatly attenuated by an optical fiber. Because of this, light on a shorter wavelength side than a short wavelength band employed as a signal light is greatly attenuated by an optical fiber, and the intensity of excitation light required for compensating for the attenuation of a signal light in a short wavelength band becomes extremely great.

On the other hand, if the intensity of excitation light is increased, the problem of Stimulated Brillouin Scattering will also occur, as in the case where an end office performs pre-emphasis and the case of a centralization amplifier. Because of this, there is a possibility that the required power cannot be input to an optical fiber.

In the case where the light intensity is made the same as the intensity of light in other wavelength bands by a centralization amplifier and pre-emphasis performed by an end office, the power is also greatly attenuated once within an optical fiber. Because of this, the optical SN ratio is degraded. Thereafter, even if the signal light is amplified, the noise component will become great and it will become difficult to reproduce the signal light.

SUMMARY OF THE INVENTION

The present invention has been made in view of the circumstances mentioned above. Accordingly, it is the primary object of the present invention to provide an optical transmission system, an optical repeater, and an optical transmission method which are capable of obtaining an equal and satisfactory optical SN ratio even at any band, in a WDM system which employs a plurality of short wavelength bands having a great attenuation due to optical fiber transmission.

To achieve the aforementioned object of the present invention and in accordance with the present invention, there is provided a first optical transmission system comprising: means for amplifying at least a specific wavelength band included in wavelength-multiplexed light propagating through a first transmission line; the means being provided between end offices and optical repeaters, between the optical repeaters, or between the first transmission line and a second transmission line disposed between the end offices.

In this manner, the interval between the repeater distances for amplifying a short wavelength band included in wavelength-multiplexed light can be made practically shorter than the interval between the repeater distances for amplifying the light in a long wavelength band. Therefore, both transmission-line loss in the short wavelength band and loss due to Stimulated Raman Scattering can be reduced.

In accordance with the present invention, there is provided a second optical transmission system comprising: a first optical repeater comprising means for exciting at least light in a short wavelength band included in wavelength-multiplexed light so that the light in the short wavelength band is distributively amplified at a first transmission line, and an amplifier for amplifying at least the short wavelength band and a long wavelength band relative to the short wavelength band by an output of the first transmission line; a second transmission line for transmitting an output of the first optical repeater; and a second optical repeater for performing backward excitation on a short wavelength band of wavelength-multiplexed light propagating through the second transmission line, and performing distributive amplification within the second transmission line.

In this manner, at the input of the optical repeater or the end office, an output difference with a signal light having other wavelengths becomes smaller and the optical SN ratio is improved. Even at a short wavelength like a specific wavelength band, transmission quality fit for use can be maintained.

In accordance with the present invention, there is provided a first optical repeater comprising: means for wavelength-multiplexing both excitation light, which distributively amplifies at least a specific wavelength band included in light propagating through a first transmission line, and the light propagating through the first transmission line; the means being provided between end offices and optical repeaters, between the optical repeaters, or between the first transmission line and a second transmission line disposed between the end offices.

In this manner, an optical repeater system with an improved optical SN ratio of a short wavelength band can be provided.

In accordance with the present invention, there is provided a second optical repeater comprising: means for exciting at least light in a short wavelength band which is included in wavelength-multiplexed light so that the light in the short wavelength band is distributively amplified at a first transmission line; and an amplifier for amplifying at least the short wavelength band and a long wavelength band relative to the short wavelength band by an output of the first transmission line, and transmitting its output on a second transmission line.

In this manner, even when the light in a short wavelength band suffers a great loss due to the difference between the section distances for amplifying a transmission signal, amplification can be performed at a short section.

In accordance with the present invention, there is provided a third optical repeater comprising: first means for wavelength-multiplexing both first excitation light, which distributively amplifies at least a specific wavelength band included in light propagating through a first transmission line, and the light propagating through the first transmission line; and second means for wavelength-multiplexing both second excitation light, which distributively amplifies at least a specific wavelength band included in light propagating through a second transmission line, and the light propagating through the second transmission line; the first means and the second means being provided between end offices and optical repeaters, between the optical repeaters, or between the first transmission line and the second transmission line disposed between the end offices.

In this manner, an optical auxiliary repeater for amplifying light present on the short wavelength side of a working wavelength band can be provided between an end office and an optical repeater for amplifying all wavelengths, or between optical repeaters. The optical SN ratio of the light on the short wavelength side is prevented from being degraded by Stimulated Raman Scattering. In addition, the optical SN ratio of the entire transmission system can be improved.

In the third optical repeater mentioned above, the first transmission line and the second transmission line are constructed so that bidirectional communication is performed with a single fiber.

In accordance with the present invention, there is provided an optical communication method wherein the interval between light amplifications of a short wavelength band included in wavelength-multiplexed light is made practi-

cally shorter than the interval between light amplifications of a long wavelength band relative to the short wavelength band.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will be described in further detail with reference to the accompanying drawings wherein:

FIG. 1 is a block diagram showing an optical repeater system of the present invention;

FIGS. 2A and 2B are diagrams used to explain Raman amplification;

FIG. 3 is a diagram used to explain the wavelength region of a signal light that is transmitted by an optical repeater system constructed according to a first embodiment of the present invention;

FIG. 4 is a block diagram showing a centralization amplifier;

FIG. 5 is a diagram showing optical fiber loss due to wavelength;

FIG. 6A is a diagram showing the results of a simulation when the band on a short wavelength side having a degraded optical SN ratio is amplified;

FIG. 6B is a diagram showing the results of a simulation when the short-wavelength band excitation light source of the optical auxiliary repeater is operated;

FIG. 7 is a diagram showing the optical SN ratio in the case where the optical auxiliary repeater is not employed, obtained based on the construction used to measure the characteristic shown in FIG. 6A and the construction used to measure the characteristic shown in FIG. 6B;

FIG. 8 is a block diagram of an optical repeater system according to a second embodiment of the present invention;

FIG. 9 is a block diagram showing a modification of the optical repeater shown in FIG. 1;

FIG. 10 is a block diagram showing a modification of the optical auxiliary repeater in which the optical auxiliary repeater of FIG. 1 and the optical auxiliary repeater of FIG. 9 are combined;

FIG. 11 is a block diagram showing a modification in which the optical auxiliary repeater of FIG. 9 and the optical auxiliary repeater of FIG. 8 are combined;

FIG. 12 is a block diagram showing an example of an optical repeater system for performing bidirectional communication between end offices;

FIG. 13 is a block diagram showing another example of the optical repeater system for performing bidirectional communication between end offices;

FIG. 14 is a block diagram showing an optical repeater system for performing bidirectional communication between end offices, the optical auxiliary repeater of FIG. 12 being constructed with a centralization amplifier;

FIG. 15 is a block diagram showing a modification in which the optical auxiliary repeaters of FIGS. 12 and 13 are combined with the optical auxiliary repeater of FIG. 14;

FIG. 16 is a block diagram showing a modification of the optical auxiliary repeater of FIG. 15; and

FIGS. 17A to 17C are diagrams used to explain pre-emphasis.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Embodiments of the present invention will hereinafter be described in detail with reference to the drawings.

An optical repeater system (optical transmission system) 1 shown in FIG. 1 is a system for transmitting a wavelength

multiplexed signal light and is equipped with end offices 30a and 30b, optical repeaters 10-1 and 10-2, and optical auxiliary repeaters 20-1, 20-2, and 20-3. The optical auxiliary repeaters 20-1, 20-2, and 20-3 are provided between the optical repeaters 10-1 and 10-2, or between the optical repeaters 10-1, 10-2 and the end offices 30a, 30b. Between the end offices 30a, 30b and the optical repeaters 10-1, 10-2, between the optical repeaters 10-1 and 10-2, or between the optical auxiliary repeaters 20-1 and 20-3 (between the end office 30a and the end office 30b), there are provided optical fibers (transmission lines) 9a to 9f.

The end office 30b on one end of the optical repeater system 1 is used for wavelength-multiplexing a plurality of signal lights, and transmitting the multiplexed signal through the optical repeater system 1 and to the end office 30a provided on the other end of the system 1. The end office 30a has nearly the same function as the end office 30b.

First, a description will be given of the wavelength bands that are employed by the optical repeater system 1.

FIG. 3 shows the wavelength region of a signal light that is transmitted by an optical repeater system 1 constructed according to a first embodiment of the present invention. With the wavelength region divided into an S+ band, an S band, a C band, and an L band from the short wavelength side, the production of the optical repeater system 1 is being examined.

Generally, the S+ band ranges from 1451.40 nm to 1482.65 nm, the S band ranges from 1489.70 nm to 1522.56 nm, the C band ranges from 1529.55 nm to 1563.86 nm, and the L band ranges from 1567.95 nm to 1604.02 nm.

At present, commercially-available optical repeater systems are employing two kinds of bands, the C band and the L band. Recently, the use of the S band is being examined. Considering a further increase in transmission capacity, there is a possibility that the S+ band on a shorter wavelength side than the wavelengths of the S band be employed to enlarge transmission capacity. In this case, a signal light in the S+ or S band suffers transmission loss doubly because of loss due to Stimulated Raman Scattering and loss on a short wavelength side due to optical fibers 9a to 9f.

Therefore, in the case where no measure against loss is taken, the optical SN ratio of a signal light in the S+ or S band becomes lower than that of a signal light in the C or L band.

Next, a description will be given of the components of the optical repeater system 1 shown in FIG. 1.

The end offices 30a, 30b are provided at both ends of the optical repeater system 1. The WDM transmission signal light, wavelength-multiplexed at the end office 30b, is transmitted through each unit constituting the optical repeater system 1, and is wavelength-demultiplexed at the end office 30a.

The optical fibers 9a to 9f are medium to carry the WDM transmission light output from the end office 30b. The optical fibers 9a to 9f of the first embodiment employ single-mode fibers most commonly used. A zero-dispersion wavelength for single-mode fibers is 1.3 μm , and as shown in FIG. 5, loss becomes minimum at 1.5 μm .

Since excitation light has a wavelength about 100 nm shorter than that of the signal light propagating through the optical fibers 9a to 9f, it becomes possible to amplify the signal light by Stimulated Raman Scattering.

The Stimulated Raman Scattering refers to scattering that occurs by the interaction between light incident on a medium and phonons (optical vibration of crystal lattices) produced by the incident light. The intensity of this scattered

light (Stokes light) is nearly the same between forward excitation and backward excitation.

To utilize the Stimulated Raman Scattering, the optical repeater system **1** is provided with amplification means for amplifying the S+ band and S band included in the wavelength-multiplexed signal light propagating through the optical fibers **9a** to **9f**. The amplification means is provided between the end offices **30a**, **30b** and the optical repeaters **10-1**, **10-2**, between the optical repeaters **10-1**, **10-2**, or between the optical fibers **9a** to **9f** (disposed between the end offices **30a**, **30b**) and the optical fibers **9a** to **9f** other than the optical fibers **9a** to **9f** disposed between the end offices **30a**, **30b**. This amplification means is realized by the optical repeaters **10-2**, **10-1** and optical fibers **9a** to **9f**, or by the optical repeaters **10-2**, **10-1**, optical fibers **9a** to **9f**, and optical auxiliary repeaters **20-1** to **20-3**.

As an example, the amplification means consists of the optical repeater **10-1** and the optical fibers **9b**, **9c**. In this case, the optical fibers **9b**, **9c** function as a first transmission line and a second transmission line, respectively.

First, a description will be given of the optical repeater **10-2**. Since the optical repeater **10-1** is the same in construction as the optical repeater **10-2**, a description of the optical repeater **10-1** is omitted to avoid redundancy.

The optical repeater **10-2** is constructed of a centralization amplifier **11**, a Raman excitation light source **13**, a coupler (second coupler) **12**.

FIG. 4 shows the centralization amplifier **11**. The centralization amplifier **11** shown in the figure is constructed of demultiplexers **11a** to **11c**, amplifiers **14a** to **14d**, and multiplexers **11d** to **11f**.

The demultiplexers **11a** to **11c** are used to separate a signal light in a short wavelength band into separate signals again. An input signal light in the S+ band, S band, C band, and L band is separated into a signal light in the C and L bands (long wavelength) and a signal light in the S+ and S bands (short wavelength) by the demultiplexer **11a**. Then, the signal light in the C and L bands are separated into a signal light in the C band and a signal light in the L band by the demultiplexer **11b**. Similarly, the signal light in the S+ and S bands are separated into a signal light in the S+ band and a signal light in the S band by the demultiplexer **11c**.

The wavelength-demultiplexed signal lights are intensively amplified within the optical fibers by the amplifiers **14a** to **14d**, respectively. Each of the amplifiers **14a** to **14d** employs an amplifier that amplifies light by performing stimulated emission by both an optical fiber doped with a rare-earth element and excitation light.

As an example of the rare-earth element doped fiber amplifier, an erbium-doped fiber (EDF) is employed for the S band, the C band, and the L band. This erbium-doped fiber is capable of increasing gain at the S band, the C band, and the L band. In addition, a thulium-doped fiber is employed for the S+ band and the S band and able to increase gain at the S+ band and the S band.

In addition, each of the amplifiers **14a** to **14d** may employ a high-nonlinear fiber such as a dispersion compensation fiber (DCF), etc., and perform Raman amplification intensively within the optical fiber. The reason for this is that the high-nonlinear fiber is used to compensate for transmission-line dispersion. The amplification band in this case is determined so that excitation light has a wavelength about 100 nm shorter than the wavelength of a signal light to be amplified.

The outputs of the amplifiers **14a**, **14b** are incorporated into a wavelength-multiplexed signal light in the C and L bands by the multiplexer **11d**. Similarly, the outputs of the

amplifiers **14c**, **14d** are incorporated into a wavelength-multiplexed signal light in the S+ and S bands by the multiplexer **11e**. Furthermore, the two wavelength-multiplexed signal lights are incorporated into a wavelength-multiplexed signal light in the S+, S, C, and L bands by the multiplexer **11f**. The wavelength-multiplexed signal light from the multiplexer **11f** is transmitted on a transmission line (optical fibers **9a** to **9f**).

Next, a description will be given of the Raman excitation light source **13** that the optical repeater **10-2** has.

The Raman excitation light source **13** is an excitation light source for amplifying the wavelength-multiplexed signal light, transmitted from the end office **30b**, distributively within the optical fiber **9e**. The signal light is transmitted through the optical fiber **9f**, the optical auxiliary repeater **20-3**, and the optical fiber **9e**. Note that, depending on the structure of the optical auxiliary repeater **20-3**, the signal light can also be amplified distributively within the optical fiber **9f**. The excitation signal light from the Raman excitation light source **13** is used to perform backward excitation on the wavelength-multiplexed signal light output to the optical fiber **9e** by the coupler **12**.

Therefore, the optical repeater **10-1** (including a modification of the optical repeater **10-1** to be described later) is provided with coupling means (Raman excitation light source **13** and WDM coupler **12**) for wavelength-multiplexing both excitation light, which distributively amplifies the S+ and S bands included in the light propagating through the optical fiber **9c**, and the light propagating through the optical fiber **9c**.

The coupling means is provided between the end offices **30a**, **30b** and the optical repeaters **10-1**, **10-2**, between the optical repeaters **10-1**, **10-2**, or between the optical fiber **9b** and the optical fiber **9c** disposed between the end offices **30a**, **30b**.

In addition, excitation light is emitted from an excitation light source, in which laser light with a plurality of wavelengths is wavelength-multiplexed, so that all the bands of the signal light transmitted from the end office **30b** are amplified.

FIG. 2 shows how backward excitation is performed by Raman amplification. The coupler **12** and the Raman excitation light source **13**, shown in FIG. 2B, are both provided on a transmission line. Excitation light emitted from the Raman excitation light source **13** is added to the signal light propagating through the optical fibers **9a** to **9f** through the coupler **12**. Because of this, a signal light traveling in an up direction (which is, for example, the direction from the end office **30a** to the end office **30b**, or the direction opposite to this) is scattered and amplified by Stimulated Raman Scattering. Unless otherwise noted, the amplification by scattering is hereinafter referred to as distributive amplification.

Next, the optical auxiliary repeaters **20-1**, **20-2**, and **20-3** (see FIG. 1) will be described with the optical auxiliary repeater **20-1**.

The optical auxiliary repeater **20-1** is constructed of a short wavelength band excitation light source **14** and a coupler (second distribution amplifier section) **12**. The wavelength of the short wavelength band excitation light source **14** is a wavelength positioned on a short wavelength side of the wavelengths of the light transmitted from the end office **30b**. That is, the wavelength is an excitation light wavelength for amplifying a band which has a great loss due to Stimulated Raman Scattering and the transmission line.

The coupler **12** is used for performing backward excitation by adding the excitation light from the excitation light source **14** to a signal light being transmitted. The coupler **12**

inputs the excitation light to the optical fiber **9b** and outputs a wavelength-multiplexed signal light from the optical fiber **9b**, to the optical fiber **9a**.

While the optical auxiliary repeater **20-1** has been described as a device for performing distributive amplification, it has the function of amplifying, in wavelength bands used for transmission, light having a wavelength greater in loss than light of other wavelengths, based on the construction of the optical repeater system **1**. Furthermore, the interval between the optical auxiliary repeaters **20-1** needs to be shorter than the interval between the repeater distances for amplifying light of wavelengths other than specific wavelengths (e.g., S+ and S bands).

The optical auxiliary repeaters **20-2** and **20-3** are nearly the same as the optical auxiliary repeater **20-1**.

Next, a description will be given of the flow of the optical repeater system **1**.

The wavelength-multiplexed light from the end office **30b** is input to the optical fiber **9b** that is a transmission line. The specific wavelength light, included in the light input to the optical fiber **9b**, is amplified by the excitation light output from the optical auxiliary repeater **20-3** and is output to the optical fiber **9e** which is a transmission line. Within this optical fiber **9e**, all the wavelengths are amplified distributively by the excitation light output from the Raman excitation light source **13** of the optical repeater **10-2**. For the output of the optical fiber **9e**, all the signal wavelength bands are amplified by the centralization amplifier **11** of the optical repeater **10-2**. The amplified light is output to the optical fiber **9d**. The specific wavelength light, included in the light input to the optical fiber **9d**, is amplified by the excitation light output from the optical auxiliary repeater **20-2** and is output to the optical fiber **9c** which is a transmission line.

Within this optical fiber **9c**, all the wavelengths are amplified distributively by the excitation light output from the Raman excitation light source **13** of the optical repeater **10-1**. For the output of the optical fiber **9c**, all the signal wavelength bands are amplified by the centralization amplifier **11** of the optical repeater **10-1**. The amplified light is output to the optical fiber **9b**.

The specific wavelength light, included in the light input to the optical fiber **9b**, is amplified by the excitation light output from the optical auxiliary repeater **20-1** and is output to the optical fiber **9a** which is a transmission line. Within this optical fiber **9a**, all the wavelengths are amplified distributively by the excitation light output from the excitation light source (not shown) of the end office **30a**. For the output of the optical fiber **9a**, all the signal wavelength bands are amplified by the centralization amplifier of the end office **30a**, whereby wavelength demultiplexing is performed.

Thus, in the optical repeater system **1**, the transmission section of light in a short wavelength band, in which loss on the short wavelength side due to Stimulated Raman Scattering and loss due to the wavelength characteristics of the optical fiber are added together, can be made shorter than the transmission section of light in a long wavelength band relative to the short wavelength band. In addition, with the distance difference between the sections in which a transmission signal is amplified, the light in the short wavelength band is amplified in a short section even when it suffers a great loss.

Therefore, at the input of the optical repeater **10-1** or the end offices **30a**, **30b**, for example, an output difference with a signal light of other wavelengths is reduced and therefore an optical SN ratio is improved. Even at a short wavelength such as the S+ band, transmission quality fit for use can be maintained.

While it has been described that for wavelengths to be amplified, all the wavelengths of the wavelength-multiplexed light from the end office **30b** are amplified by the excitation light emitted from the Raman excitation light sources **13** of the optical repeaters **10-2** and **10-1**, only a band on a short wavelength side in which an optical SN ratio is degraded may be amplified.

FIG. 6A shows the results of simulations when bands on a short wavelength side having a degraded optical SN ratio are amplified. The condition for obtaining the results shown in FIG. 6A is to omit the optical auxiliary repeater **20-1** from the optical repeaters **10-2** and **10-1**, and there are shown light intensity characteristics when the Raman excitation light source **13** of the optical repeater **10-1** is used as an excitation light source for amplifying the S+ band which is on a short wavelength side. In addition, the repeater section between the optical repeater **10-2** and the optical repeater **10-1** is 100 km. The solid line represents the S+ band and the broken line the L band. Compared with the L band, the S+ band is greatly attenuated by both the influence of Stimulated Raman Scattering and the influence of the loss characteristic of the optical fiber. However, the light intensity of the S+ band is improved from a position of about 70 km by the backward excitation performed by the optical repeater **10-1**, and becomes equal to the light intensity of the L band at a position of 100 km.

Therefore, the wavelength of the excitation light source for distributive amplification, provided in the optical repeater **10-1**, is made equal to a wavelength that amplifies light present in a short wavelength band where Stimulated Raman Scattering loss and optical-fiber loss are added. In this manner, a light intensity difference with light in a long wavelength band is reduced on a transmission line. In addition, the light intensities at the transmission line end are made the same, whereby the optical SN ratio difference between wavelengths is improved.

FIG. 6B shows the results of simulations when the short wavelength band excitation light source **14** of the optical auxiliary repeater **20-1** is operated, in the case where, on the transmission lines between the optical repeaters **10-2**, **10-1** and optical auxiliary repeater **20-1** of FIG. 1, the Raman excitation light source **13** of the optical repeater **10-1** is used to excite the wavelengths in the S+ band which is on a short wavelength side, as described above.

Suppose the case where the distance between the optical repeater **10-2** and the optical repeater **10-1** is, for example, 100 km and the optical auxiliary repeater **20-1** is provided at a position 50 km away from the optical repeater **10-2**. In FIG. 6B, the solid line represents the S+ band and the broken line the L band.

The light in the S+ band is more greatly attenuated than the light in the L band. However, at a position 50 km away from the optical repeater **10-2**, the intensity of the light in the S+ band is amplified distributively by the excitation light from the optical auxiliary repeater **20-2** and becomes equal to the intensity of the light in the L band.

The light in the S+ and output from the optical auxiliary repeater **20-1** is more greatly attenuated than the light in the L band again. However, the light in the S+ band is amplified distributively at a position near about 80 km by the excitation light emitted from the optical repeater **10-1**, and the intensity of the light in the S+ band exceeds the intensity of the L band at a position exceeding 90 km.

Therefore, the optical repeater system **1** is provided with (1) the optical repeater **10-2** (first optical repeater), which consists of the Raman excitation light source **13** for exciting the light in a short wavelength band, included in wave-

length-multiplexed light, so that it is distributively amplified at the optical fiber **9e**, and the centralization amplifier **11** for amplifying both a short wavelength band and a long wavelength band relative to the short wavelength band by use of the output of the optical fiber **9e** and for outputting the amplified light to the optical fiber **9d**; (2) the optical fiber **9b** for transmitting the output of the optical repeater **10-2**; and (3) the optical repeater (second optical repeater) **10-1** for performing backward excitation on the short wavelength band of the wavelength-multiplexed light being transmitted through the optical fiber **9b** to perform distributive amplification within the optical fiber **9b**.

Thus, the light being transmitted is amplified within the optical fiber by the excitation light output from the optical auxiliary repeater before the light intensity on the short wavelength side is greatly degraded. Because of this, the attenuated quantity of the signal in the S+ band is reduced and therefore the optical SN ratio viewed from the optical repeater **10-1** is improved.

FIG. 7 shows the optical SN ratio in the case where the optical auxiliary repeater **20-1**, etc., are not employed, obtained based on the construction used to measure the characteristic shown in FIG. 6A and the construction used to measure the characteristic shown in FIG. 6B.

In the case where the optical auxiliary repeater **20-1**, etc., are not employed, the S+ band is appreciably attenuated by Stimulated Raman Scattering and the attenuation characteristic of the optical fiber, and therefore the optical SN ratio is greatly degraded. On the other hand, in the case where the optical auxiliary repeater **20-1**, etc., are employed, attenuation due to the S+ band transmission line can be reduced and therefore the degradation of the optical SN ratio is alleviated.

The reason why the optical SN ratios for the S, C, and L bands are improved is that the power in the short wavelength band is absorbed on the long wavelength side by Stimulated Raman Scattering and therefore the light intensities are increased.

The conditions to calculate the optical SN ratios shown in FIG. 7 are as follows. For the input power to the optical fiber, the S+ and S bands are -2 dBm/ch and the C band -3.5 dBm/ch, and the L band is -4.5 dBm/ch. The optical fiber is a single-mode fiber and the length is 100 km. In addition, the wavelength of the excitation light used for distributive amplification of the S+ band ranges from 1.356 nm to 1.381 nm. Note that dBm/ch represents power per channel.

The output power of the excitation light for the S+ band required excitation of $+27$ dBm when the optical auxiliary repeater **20-1**, etc., were not provided between the optical repeaters **10-1** and **10-2**. In the case the optical auxiliary repeater **20-1**, etc., were provided between the optical repeaters **10-1** and **10-2**, the main powers to the excitation light source for distributive amplification with respect to the optical repeater **10-1** and the optical auxiliary repeater **20-1** were 24 dBm, respectively.

Thus, even if the signal light in the short wavelength band from each excitation light source is weakened by Stimulated Raman Scattering and losses due to the optical fibers **9a** to **9f** when transmitted through the optical fibers **9a** to **9f**, the light intensity of the S+ band within the optical fibers **9a** to **9f** is not greatly attenuated with respect to other wavelength bands, because the distribution amplifier is provided between the optical repeaters **10-1** and **10-2** to compensate for the light intensity. This improves the optical SN ratio.

Therefore, in the WDM transmission system employing the S+, S, C, and L bands, a difference in the optical SN ratio due to a difference between the wavelengths of the signal light can be alleviated.

In the optical repeater system **1**, while it has been described that the distributive amplification by the optical auxiliary repeater is performed by the backward excitation of a signal light, it may be constructed so that forward excitation is performed.

FIG. 2A shows how forward excitation is performed. A signal light, and the light from the Raman short wavelength band excitation light source **14**, are wavelength-multiplexed by the coupler **12** so that they propagate in the same direction, whereby distributive amplification can be performed within the transmission line by forward excitation. As a distributive amplification method, distributive amplification by backward excitation and distributive amplification by forward excitation, with respect to the optical auxiliary repeater between the optical repeaters, are employed.

FIG. 8 shows an optical repeater system constructed according to a second embodiment of the present invention. The optical repeater system **1a** shown in the figure is constructed of optical repeaters **10a-1** and **10a-2** and optical auxiliary repeaters **20a-1**, **20a-2**, and **20a-3**. Note in FIG. 8 that the parts with the same reference numerals as those of FIG. 1 have the same or similar function.

The optical auxiliary repeaters **20a-1**, **20a-2** are equipped with short-wavelength band excitation light sources **14-1** and **14-2** for amplifying a short wavelength band component, and couplers **12-1**, **12-2**. A signal light and excitation light are wavelength-multiplexed at the couplers **12-1** and **12-2**, whereby forward excitation and backward excitation are both performed on the signal light.

This can further reduce loss due to Stimulated Raman Scattering and loss in the short wavelength band light having a great loss due to optical fibers, and therefore can reduce the output of the excitation light that is emitted from the short-wavelength band excitation light source **14**.

Furthermore, as in the optical repeaters **10a-1** and **10a-2** shown in FIG. 8, the Raman excitation light sources **13** can be provided across the centralization amplifier **11** in order to perform distributive amplification, and a signal light and excitation light can be wavelength-multiplexed at the coupler **12**. In addition, the optical repeaters **10-1** and **10-2** shown in FIG. 1, which have the centralization amplifier **11** for performing distributive amplification by backward excitation, can also be employed. The excitation light sources of the optical repeaters **10-1**, **10-2** may be constructed so that all the wavelengths of a signal light from the end office **30b** are amplified or only the short wavelength band component is amplified.

Therefore, between the end offices **30a**, **30b** and the optical repeaters **10-1**, **10-2**, between the optical repeaters **10-1**, **10-2**, or between the optical fibers **9b**, **9c** disposed between the end offices **30a**, **30b**, the optical repeater **10a-1** has (1) first coupling means (WDM coupler **12** and Raman excitation light source **13**) for wavelength-multiplexing both the excitation light, output from the first Raman excitation light source **13** for distributively amplifying the S+ and S bands included in the signal light propagating through the optical fiber **9c**, and the signal light propagating through the optical fiber **9c**, and (2) second coupling means (WDM coupler **12** and Raman excitation light source **13**) for wavelength-multiplexing both the excitation light, output from the second Raman excitation light source **13** for distributively amplifying the S+ and S bands included in the signal light propagating through the optical fiber **9b**, and the signal light propagating through the optical fiber **9b**.

In addition, between the end offices **30a**, **30b** and the optical repeaters **10-1**, **10-2**, between the optical repeaters

10-1, 10-2, or between the optical fibers **9e, 9d** disposed between the end offices **30a, 30b**, the optical repeater **10b-2** has (1) first coupling means (WDM coupler **12** and Raman excitation light source **13**) for wavelength-multiplexing both the excitation light, output from the first Raman excitation light source **13** for distributively amplifying the S+ and S bands included in the signal light propagating through the optical fiber **9e**, and the signal light propagating through the optical fiber **9e**, and (2) second coupling means (WDM coupler **12** and Raman excitation light source **13**) for wavelength-multiplexing both the excitation light, output from the second Raman excitation light source **13** for distributively amplifying the S+ and S bands included in the signal light propagating through the optical fiber **9d**, and the signal light propagating through the optical fiber **9d**.

As a modification, the optical repeaters **10-1** and **10-2** shown in FIG. 1 can also be employed.

FIG. 9 shows a modification of the optical repeater **10-1** shown in FIG. 1, distributive amplification being performed at the transmission line shown in FIG. 1. On the other hand, the modification shown in FIG. 9 employs a centralization amplifier. Note in FIG. 9 that the same reference numerals are applied to the same parts as those of FIG. 1 to avoid redundancy.

The wavelength-multiplexed signal light from the optical fiber **9d** (transmission line) is separated into a signal light in S+ band (light in a short wavelength band) and a signal light in other bands by the WDM coupler **17a** provided within an optical auxiliary repeater **20b-2**. The signal light in the S+ band, separated at the WDM coupler **17a**, is input to a centralization amplifier **17b** for a short wavelength band and is amplified. The centralization amplifier **17b** employs a centralization Raman amplifier, constructed of a rare-earth element doped fiber such as an erbium-doped fiber (EDF), etc., or a high-nonlinear fiber such as a dispersion compensation fiber (DCF), etc.

The output, other than the S+ band, of the WDM coupler **17a** and the output of the centralization amplifier **17b** are multiplexed at a WDM coupler **17c** and output to an optical fiber **9c** (transmission line).

Thus, a signal light in a short wavelength band like the S+ band, whose fiber loss characteristic is great and which is susceptible to a Stimulated Raman Scattering tilt, is amplified between the optical repeaters. Because of this, transmission loss is reduced and an optical SN ratio difference with other wavelengths is improved.

An optical repeater system **1d** shown in FIG. 10 includes the part of the optical auxiliary repeater shown in FIG. 1 and the part of the optical auxiliary repeater shown in FIG. 9. In an optical auxiliary repeater **20d-1** shown in FIG. 10, the construction of the optical auxiliary repeater **20-1** of FIG. 1 which performs backward excitation is combined with the side of the optical fiber **9d** of the optical auxiliary repeater **20b-2** shown in FIG. 9. In FIG. 10, parts with the same reference numerals as those shown in FIGS. 1 and 9 have the same or similar function, and therefore a further description thereof is not given.

The optical repeaters **10a-2** and **10a-1** shown in FIG. 10 employs the optical repeaters shown in FIG. 8 and, depending on conditions of the optical repeater system **1d**, can also employ the optical repeaters **10-2** and **10-1** of FIG. 1.

The optical repeater system **1e** shown in FIG. 11 is a modification combining the optical auxiliary repeater **20b-2** of FIG. 9 and the optical auxiliary repeater **20a-2** of FIG. 8 together. The optical auxiliary repeater **20d-2** shown in FIG. 11 is equipped with a WDM coupler **12-2** (see FIG. 8) for performing forward excitation on a signal light, a WDM

coupler **12-1** (see FIG. 8) for performing backward excitation on a signal light, and a centralization amplifier (see FIG. 9) for intensively amplifying light in a short wavelength band, provided between the WDM couplers **12-1** and **12-2**. The optical repeaters **10a-1** and **10a-2** shown in FIG. 11 are provided with Raman excitation light sources **13, 13** for performing forward excitation and backward excitation on a signal light.

Note in FIG. 11 that the same reference numerals are applied to the same parts as those of FIGS. 8 and 9 to avoid redundancy.

In FIG. 11, the optical repeater **10a-2** will be described.

The optical repeater **10a-2** has a WDM coupler **12** on the output side of a centralization amplifier **11**, and outputs excitation light from a Raman excitation light source **13**, to an optical fiber **9d** so that distributive amplification is performed on the signal light propagating through the optical fiber **9d** by forward excitation.

The optical repeater **10a-2** is constructed so that it performs both forward excitation and backward excitation. However, the optical repeater **10a-2** can also utilize a combination of distributive amplification, based on backward excitation, and a centralization amplifier (such as the optical repeater **10-1** of FIG. 1), or a combination of distributive amplification, based on forward excitation, and a centralization amplifier.

Next, a bidirectional communication system will be described with reference to FIGS. 12 to 16.

The optical repeater system **1b** shown in FIG. 12 performs bidirectional communication between an end office **30a** and an end office **30b**. The optical repeater system **1b** shown in FIG. 12 includes optical repeaters **10b-1, 10b-2**, each of which is provided with two kinds of optical circulators (separating sections) **31-a, 31-b**. The signal lights coming from the optical fibers **9e, 9d** are circulated through centralization amplifier **11-a** and **11-b** by the optical circulators **31-a, 31-b** and are amplified, whereby bidirectional communication is performed.

Since the optical repeaters **10b-1, 10b-2** have nearly the same function, a description will be given of the optical repeater **10b-1**.

The signal light from an optical fiber **9c** enters a WDM coupler **12** and is output to the optical circulator **31-a**. This optical circulator **31-a** outputs the light from the WDM coupler **12**, to a centralization amplifier **11-a**. The output of the centralization amplifier **11-a** is input to an optical circulator **31-b**. The optical circulator **31-b** outputs the light from the centralization amplifier **11-a**, to a WDM coupler **12**. The WDM coupler **12** outputs the light output from the optical circulator **31-b**, to the optical fiber **9b**.

On the other hand, the signal light from the optical fiber **9b** enters the WDM coupler **12** within the optical repeater **10b-1** and is output to the optical circulator **31-b**. The optical circulator **31-b** outputs the light from the WDM coupler **12**, to the centralization amplifier **11-b**. The output of the centralization amplifier **11-b** is input to the optical circulator **31-a**. The optical circulator **31-a** outputs the light from the centralization amplifier **11-b**, to the WDM coupler **12**. The WDM coupler **12** outputs the light from the optical circulator **31-a**, to the optical fiber **9c**. The centralization amplifiers **11-a** and **11-b** in this case have, for example, a construction such as that shown in FIG. 4, and separate the light ranging from the S+ band to the L band into the respective bands and performs amplification.

Thus, the optical repeaters **10b-1, 10b-2** can perform bidirectional communication by employing, for example, a single optical fiber consisting of the optical fibers **9c, 9d**.

Again, in FIG. 12, the Raman excitation light source 13 for distributive amplification outputs excitation light to the optical fibers 9b, 9c through the WDM coupler 12. The signal lights within the optical fibers 9b, 9c are distributively amplified. More specifically, the excitation light that is emitted by the Raman excitation light source 13 may have wavelengths which amplify light of all wavelengths, or a wavelength which amplifies the light in a band, such as the S+ band, susceptible to a simulated Raman scattering tilt and great fiber attenuation.

In the optical repeater 10b-1 (or 10b-2), the reason why the signal light from the end office 30a (or 30b) is isolated within the optical repeater 10b-1 (or 10b-2) by the optical circulator 31-b (or 31-a) is that the centralization amplifier is provided with an optical isolator (not shown). That is, since an optical isolator regulates the propagating direction of light, when bidirectional communication is performed there is a need to perform isolation of a signal light within the optical repeater.

Next, the construction of the optical auxiliary repeaters of the optical repeater system 1b will be described with the optical auxiliary repeater 20a-2 as an example. The construction of the optical auxiliary repeater 20a-2 is the same as that of the optical auxiliary repeater 20a-2 of FIG. 8. This optical auxiliary repeater 20a-2 excites a signal light in the S+ band (short wavelength) with respect to the optical fibers 9c, 9d to perform distributive amplification on the signal light. Within the optical fibers 9c, 9d, the signal lights from the end offices 30a, 30b are distributively amplified, respectively.

Next, a description will be given of the end offices 30a, 30b shown in FIG. 12.

The end offices 30a, 30b multiplex signal lights ranging from the S+ band to the L band so that the respective channel wavelengths (frequencies) do not coincide, and output the multiplexed signal lights to the optical fibers 9a, 9f.

Thus, according to the optical communication method of the present invention, the interval between light amplifications of the short wavelength band included in wavelength-multiplexed light can be made practically shorter than the interval between light amplifications of a long wavelength band relative to the short wavelength band.

Thus, by changing the structure of the optical repeaters of the optical repeater system 1b, the light in the short wavelength band is amplified at a practically shorter distance than the distance traveled by the light in the long wavelength band. This can reduce various losses that occur when transmission is performed through optical fibers, and bidirectional optical communication with an improved optical SN ratio in the short wavelength band based on the above-mentioned embodiment can be made possible.

FIG. 13 shows the construction of an optical repeater in the case of constituting a bidirectional system. The optical repeater system 1c shown in FIG. 13 is differentiated from the optical repeater system 1b shown in FIG. 12 in that the construction of the optical repeater differs. The remaining construction is the same as that shown in FIG. 12.

The optical repeaters 10c-1 and 10c-2 of the optical repeater system 1c shown in FIG. 13 will hereinafter be described with reference to the optical repeater 10c-1. The optical repeater 10c-1 inputs the light from an optical fiber (transmission line) 9c, to an optical circulator 31-a. The optical circulator 31-a outputs the light from the optical fiber 9c, to a centralization amplifier 11-a. The centralization amplifier 11-a amplifies the light output from the optical circulator 31-a and outputs the amplified light to a WDM

coupler 12. The centralization amplifier 11-a can employ the centralization amplifier described in the above-mentioned embodiments.

The WDM coupler 12 receives the light from the centralization amplifier 11-a and the light from a Raman excitation light source 13 and outputs the multiplexed light to an optical circulator 31-b. The excitation wavelength of the Raman excitation light source 13 may be a wavelength which excites the light in a short wavelength band, or wavelengths which excite the light in all wavelength bands. The optical circulator 31-b outputs the light from the WDM coupler 12, to the optical fiber 9b which is a transmission line.

On the other hand, the light from the optical fiber 9b is input to the optical circulator 31-b. The optical circulator 31-b outputs the light from the optical fiber 9b, to the centralization amplifier 11-b. The centralization amplifier 11-b amplifies the light output from the optical circulator 31-b and outputs the amplified light to a WDM coupler 12. The centralization amplifier 11-b can employ the centralization amplifier 11 described in the above-mentioned embodiments.

The WDM coupler 12 receives the light from the centralization amplifier 11-b and the light from a Raman excitation light source 13 and outputs the multiplexed light to the optical circulator 31-a. The excitation wavelength of the Raman excitation light source 13 may be a wavelength which excites the light in a short wavelength band, or wavelengths which excite the light in all wavelength bands. The optical circulator 31-a outputs the light from the WDM coupler 12, to the optical fiber 9c which is a transmission line.

The reason why the signal lights from the end office 30a, 30b are isolated within the optical repeater by the optical circulator 31-a is that the centralization amplifier is provided with an optical isolator (not shown). That is, since an optical isolator regulates the propagating direction of light, when bidirectional communication is performed there is a need to perform isolation of a signal light within the optical repeater.

Thus, by changing the structure of the optical repeater, bidirectional optical communication with an improved optical SN ratio in the short wavelength band based on the above-mentioned embodiment can be rendered possible.

Next, an optical repeater system 1h shown in FIG. 14 is constructed so that in the constructions of FIGS. 12 and 13 in which bidirectional communication is performed between the end offices 30a and 30b, the optical auxiliary repeater 20a-2 of FIG. 12 is constructed with a centralization amplifier. A description will hereinafter be described with reference to an optical auxiliary repeater 20e-2.

The optical auxiliary repeater 20e-2 inputs the signal light from an optical fiber 9d, to a first optical auxiliary repeater 17-1 having the same construction as the optical auxiliary repeater 20b-2 of FIG. 9 by an optical circulator 31a, and outputs the output of the first optical auxiliary repeater 17-1 to an optical fiber 9c through an optical circulator 31b. The optical auxiliary repeater 20e-2 also inputs the signal light from an optical fiber 9c, to a second optical auxiliary repeater 17-2 having the same construction as the optical auxiliary repeater 20b-2 of FIG. 9 by an optical circulator 31b, and outputs the output of the second optical auxiliary repeater 17-2 to the optical fiber 9c through the optical circulator 31b.

Since the first optical auxiliary repeater 17-1 and the second optical auxiliary repeater 17-2 are the same as the optical auxiliary repeater 20b-2, a description thereof is not given to avoid redundancy.

In addition, the optical repeaters **10b-2**, **10b-1** are the same as the optical repeaters **10b-2**, **10b-1** of FIG. 12, so a description thereof is not given. Instead of the optical repeaters **10b-2**, **10b-1**, the optical repeaters **10c-2**, **10c-1** of FIG. 13 can be employed.

In an optical repeater system as shown in FIG. 15, optical auxiliary repeaters **10b-1**, **10b-2** (see FIG. 12) and optical auxiliary repeaters **10c-1**, **10c-2** (see FIG. 13) are combined with the optical auxiliary repeaters **20e-2** shown in FIG. 14, respectively. At the ends of the two optical fibers **9d** and **9c** of the optical auxiliary repeater **20e-2** shown in FIG. 15, there are provided WDM couplers **12**. A WDM coupler **12** on the side of the optical fiber **9d** receives the excitation light from a short-wavelength band excitation light source **14** and inputs the excitation light to the optical fiber **9d**. Similarly, a WDM coupler **12** on the side of the optical fiber **9c** receives the excitation light from a short-wavelength band excitation light source **14** and inputs the excitation light to the optical fiber **9c**.

As a result, the signal lights within the optical fibers **9d**, **9c** are excited by the excitation light sources **14** and are Raman-amplified.

Note that the optical auxiliary repeater **20e-2** of FIG. 14 can be provided between the WDM couplers **12** shown in FIG. 15. Although the optical repeater system **1f** of FIG. 15 employs the same optical repeaters as those of FIG. 12, it can also employ the same optical repeaters as those of FIG. 13.

An optical repeater system **1g** shown in FIG. 16 is a modification of the optical auxiliary repeater **20e-2** of FIG. 15. In the optical auxiliary repeater **20e-2** shown in FIG. 15, the excitation light source **14** for Raman amplification of a short wavelength band emits excitation light to the optical fibers **9d**, **9c** through the WDM couplers **12** provided between the optical circulators **31a**, **31b** and the optical fibers **9d**, **9c**.

On the other hand, in an optical auxiliary repeater **20f-2** shown in FIG. 16, a WDM coupler **12** is provided between a first optical auxiliary repeater **17-1** and an optical circulator **31b**, and the amplified output of the first optical auxiliary repeater **17-1** and the excitation light from a short-wavelength band excitation light source **14** are output to an optical fiber **9c** through the optical circulator **31b**.

Similarly, a WDM coupler **12** is provided between a second optical auxiliary repeater **17-2** and an optical circulator **31a**, and the amplified output of the second optical auxiliary repeater **17-2** and the excitation light from a short-wavelength band excitation light source **14** are output to an optical fiber **9d** through the optical circulator **31a**.

The first optical auxiliary repeater **17-1** and the second optical auxiliary repeater **17-2** are the same as those shown in FIGS. 9, 14, and 15, so a description thereof is not given to avoid redundancy.

In addition, the optical repeaters **10c-1**, **10c-2** are the same as that shown in FIG. 13, so a description thereof is not given to avoid redundancy. Furthermore, the optical repeaters **10c-1**, **10c-2** may employ those shown in FIG. 12.

While the present invention has been described with reference to the preferred embodiments thereof, the invention is not to be limited to the details given herein, but may be modified within the scope of the invention hereinafter claimed.

For example, the optical auxiliary repeater shown in FIGS. 1, 8, 9, 10, 11, 12, 13, 14, 15, or 16 can be provided between the end office and the optical repeater, between the

optical repeaters, or between the optical fibers (transmission lines) disposed between the end offices.

The optical repeater and the optical auxiliary repeater can employ combination of the optical repeater and optical auxiliary repeater described in FIGS. 1 and 8 to 16.

Furthermore, in the optical repeaters and optical auxiliary repeaters of FIGS. 8 and 11 to 16 and the optical repeater of FIG. 14, an optical repeater system with excitation light for Raman amplification within a plurality of optical repeaters may be constructed so that the excitation light from a single excitation light source is divided into two parts which are supplied to two different WDM couplers.

The invention claimed is:

1. An optical transmission system amplifying wavelength division multiplexed light which includes lights in a first specific wavelength band and a second specific wavelength band wavelength multiplexed together, the optical transmission system comprising:

a first set of amplifiers Raman amplifying the lights in the first specific wavelength band as the wavelength division multiplexed light travels through a transmission line, the amplifiers of the first set being spaced apart from each other by a first interval; and

a second set of amplifiers Raman amplifying the lights in the first specific wavelength band and the lights in the second specific wavelength band as the wavelength division multiplexed light travels through the transmission line, the amplifiers of the second set being spaced apart from each other by a second interval, wherein the first interval is shorter than the second interval, and the first and second intervals together with amplification provided by the first and second sets of amplifiers causing light intensities of the lights in the first specific wavelength band and lights in the second specific wavelength band to become the same at an end of the transmission line.

2. An optical transmission system comprising:

a plurality of amplifiers, each of which is connected with first and second transmission lines disposed between an end office and an optical repeater, between two optical repeaters, or between two end offices and is operable to amplify a specific wavelength band included in a wavelength-multiplexed light propagating through the first transmission line, each of the amplifiers including coupling means for wavelength-multiplexing an excitation light which distributively amplifies the specific wavelength band,

wherein said plurality of amplifiers include

at least two first amplifiers for amplifying at least a first specific wavelength band, in which band a loss due to Stimulated Raman Scattering and a loss due to wavelength characteristics of optical fiber are added together, and

at least two second amplifiers for amplifying at least a second specific wavelength band, whose wavelengths are longer than the wavelengths of the first specific wavelength band, and

a first interval between said first amplifiers is set shorter than a second interval between said second amplifiers in such a manner that in the first transmission line, a difference between the light intensity of the first specific wavelength band and the light intensity of the second specific wavelength band is reduced.

3. The optical transmission system as set forth in claim 2, wherein at least one of said first amplifiers and at least one of said second amplifiers are combined in a single amplifier.

4. An optical transmission method in an optical transmission system comprising one or more amplifiers, each of which is connected with first and second transmission lines disposed between an end office and an optical repeater, between two optical repeaters, or between two end offices, and is operable to amplify at least light in a specific wavelength band included in a wavelength-multiplexed light propagating through the first transmission line, said optical transmission method comprising:

a first amplifying step of amplifying at least light in a first specific wavelength band, in which band a loss due to Stimulated Raman Scattering and a loss due to wavelength characteristics of optical fiber are added together, by first excitation light each outputted from first excitation light sources arranged at a first interval, and

a second amplifying step of amplifying at least light in a second specific wavelength band, whose wavelengths are longer than the wavelengths of the first specific wavelength band, by second excitation light each outputted from second excitation light sources arranged at a second interval,

wherein the first interval in said first amplifying step is set shorter than the second interval in said second amplifying step in such a manner that a difference between the light intensity of the first specific wavelength band in said first amplifying step and the light intensity of the second specific wavelength band in said second amplifying step is reduced.

5. An optical transmission system comprising:

a plurality of amplifiers, each of which is connected with first and second transmission lines disposed between an end office and an optical repeater, between two optical repeaters, or between two end offices and is operable to amplify a specific wavelength band included in a wavelength-multiplexed light propagating through the first transmission line,

wherein said plurality of amplifiers include

at least two first amplifiers for amplifying at least a first specific wavelength which has a great loss due to Stimulated Raman Scattering (SRS) and said first transmission line, and

at least two second amplifiers for amplifying at least a second specific wavelength and, whose wavelengths are longer than the wavelengths of the first specific wavelength band, and

a first interval between said first amplifiers is set shorter than a second interval between said second amplifiers in such a manner that in the first transmission line, a difference between the light intensity of the first specific wavelength band and the light intensity of the second specific wavelength band is reduced.

6. An optical repeater provided for an optical transmission system comprising one or more amplifiers, each of which is connected with two transmission lines disposed between an end office and an optical repeater, between two optical

repeaters, or between two end offices, and is operable to amplify at least a specific wavelength band included in a wavelength-multiplexed light propagating through one of the associated transmission lines, said optical repeater being connected with first and second transmission lines and comprising:

an exciter for outputting an excitation light which distributively amplifies a first specific wavelength band; each amplifier for amplifying at least the first specific wavelength band and a second specific wavelength band, whose wavelengths are longer than the wavelengths of the first specific wavelength band, and transmits said first and second wavelength bands on the second transmission line disposed between said end offices, such that a first interval between a first set of amplifiers is shorter than a second interval between a second set of amplifiers which amplify light of wavelengths other than said first specific wavelength band, and

wherein the first interval in said first set of amplifiers is set shorter than the second interval in the second set of amplifiers in such a manner that a difference between the light intensity of the first specific wavelength band in said first set of amplifiers and the light intensity of the second specific wavelength band in said second set of amplifiers is reduced.

7. An optical transmission system comprising one or more amplifiers, each of which is connected with first and second transmission lines disposed between an end office and an optical repeater, between two optical repeaters, or between two end offices, and is operable to amplify at least a specific wavelength band included in a wavelength-multiplexed light propagating through the first transmission line, said optical transmission system comprising:

a first set of amplifiers amplifying at least light in a first specific wavelength band, in which band a loss due to Stimulated Raman Scattering and a loss due to wavelength characteristics of optical fiber are added together, by first excitation light each outputted from first excitation light sources arranged at a first interval, and

a second set of amplifiers amplifying at least light in a second specific wavelength band, whose wavelengths are longer than the wavelengths of the first specific wavelength band, by second excitation light each outputted from second excitation light sources arranged at a second interval,

wherein the first interval in said first set of amplifiers is set shorter than the second interval in said second set of amplifiers in such a manner that a difference between the light intensity of the first specific wavelength band in said first amplifying step and the light intensity of the second specific wavelength band in said second amplifying step is reduced.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 7,075,709 B2
APPLICATION NO. : 10/103690
DATED : July 11, 2006
INVENTOR(S) : Kentaro Nakamura et al.

Page 1 of 1

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:


Title Page, Col. 1, (56) References Cited

U.S. Patent Documents

Col. 1, line 2, after "6,574,037" delete "B1" and insert --B2--.
Col. 1, line 3 after "6,587,259" delete "B1" and insert --B2--.
Col. 1, line 4, after "6,614,586" delete "B1" and insert --B2--.

Signed and Sealed this

Twenty-first Day of November, 2006

A handwritten signature in black ink on a light gray dotted background. The signature reads "Jon W. Dudas" in a cursive style.

JON W. DUDAS

Director of the United States Patent and Trademark Office